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**Sakamoto**

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(54) **LINEAR DRIVE ULTRASONIC MOTOR**

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(30) **Foreign Application Priority Data**

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(51) **Int. Cl.**  
**H01L 41/08** (2006.01)

(52) **U.S. Cl.** ..... **310/323.02**

(58) **Field of Classification Search** ..... 310/323.02  
See application file for complete search history.

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(57) **ABSTRACT**

There is provided a linear drive ultrasonic motor of which, a size can be made small, and in which, it is possible to guide assuredly while reducing a transfer resistance and a frictional resistance of a driven member.

A linear drive ultrasonic motor includes at least, an ultrasonic vibrator having a piezoelectric element, a driven member which is driven by a frictional force between the driven member and the ultrasonic vibrator, a pressing member which presses the ultrasonic vibrator such that a frictional force is generated between the ultrasonic vibrator and the driven member, a rolling member having a spherical shape, which makes a contact with the driven member, and a base member which movably supports the driven member via the rolling member, and the rolling member makes a contact with the driven member at a first contact point, and makes a contact with the base member at two second contact points, and lengths of two straight lines connecting the first contact point and two second contact points are substantially same.

**9 Claims, 22 Drawing Sheets**

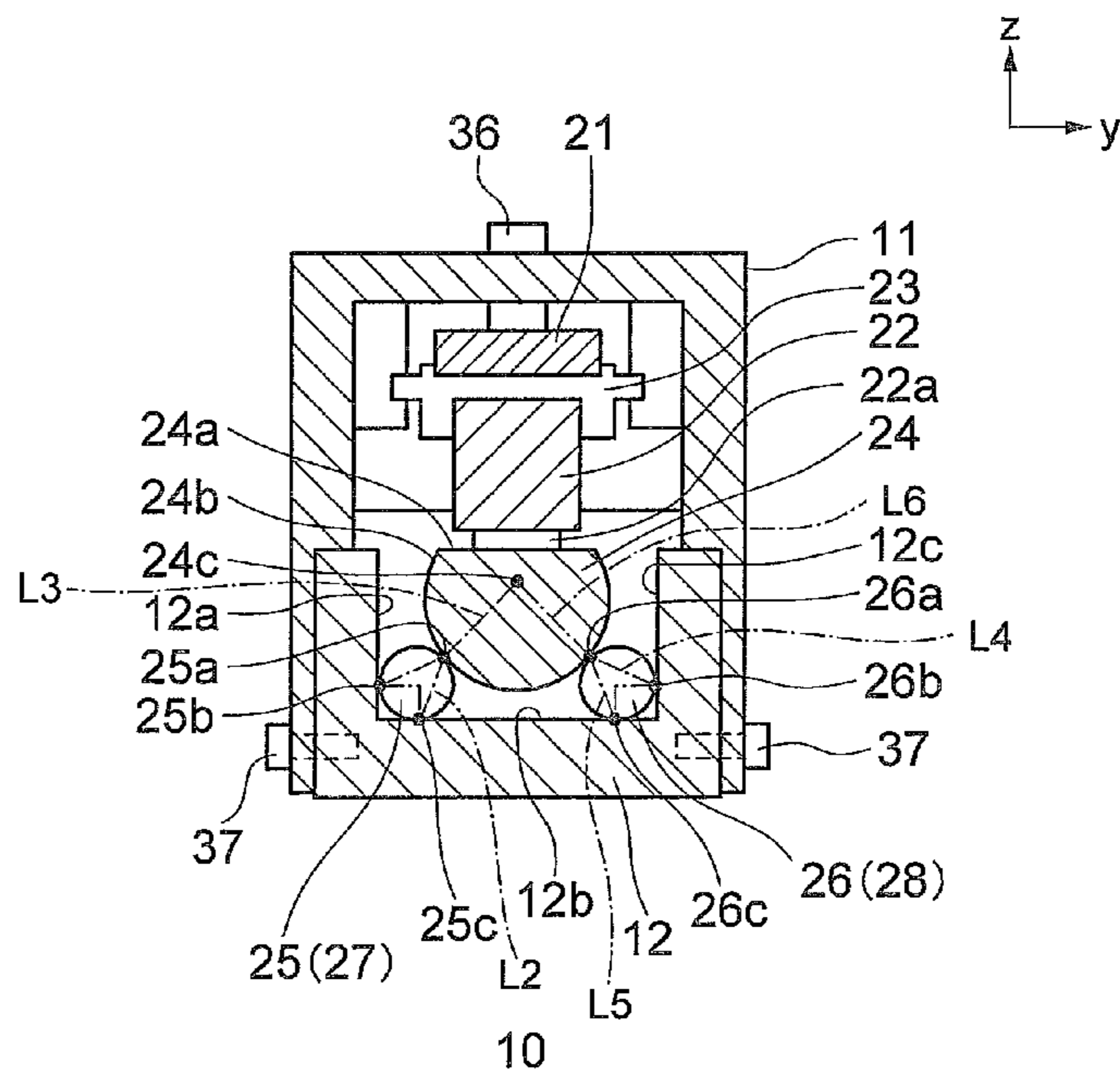
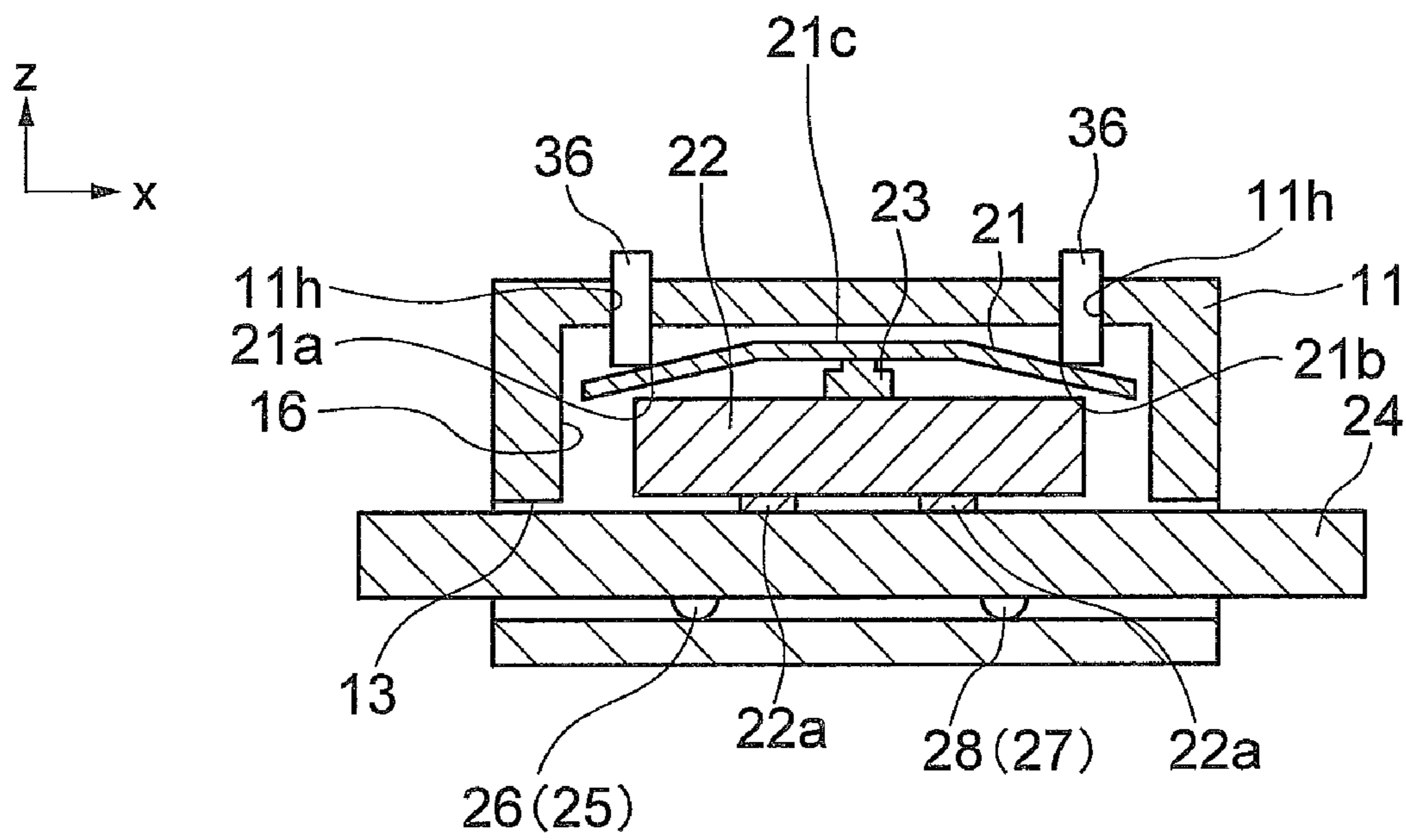
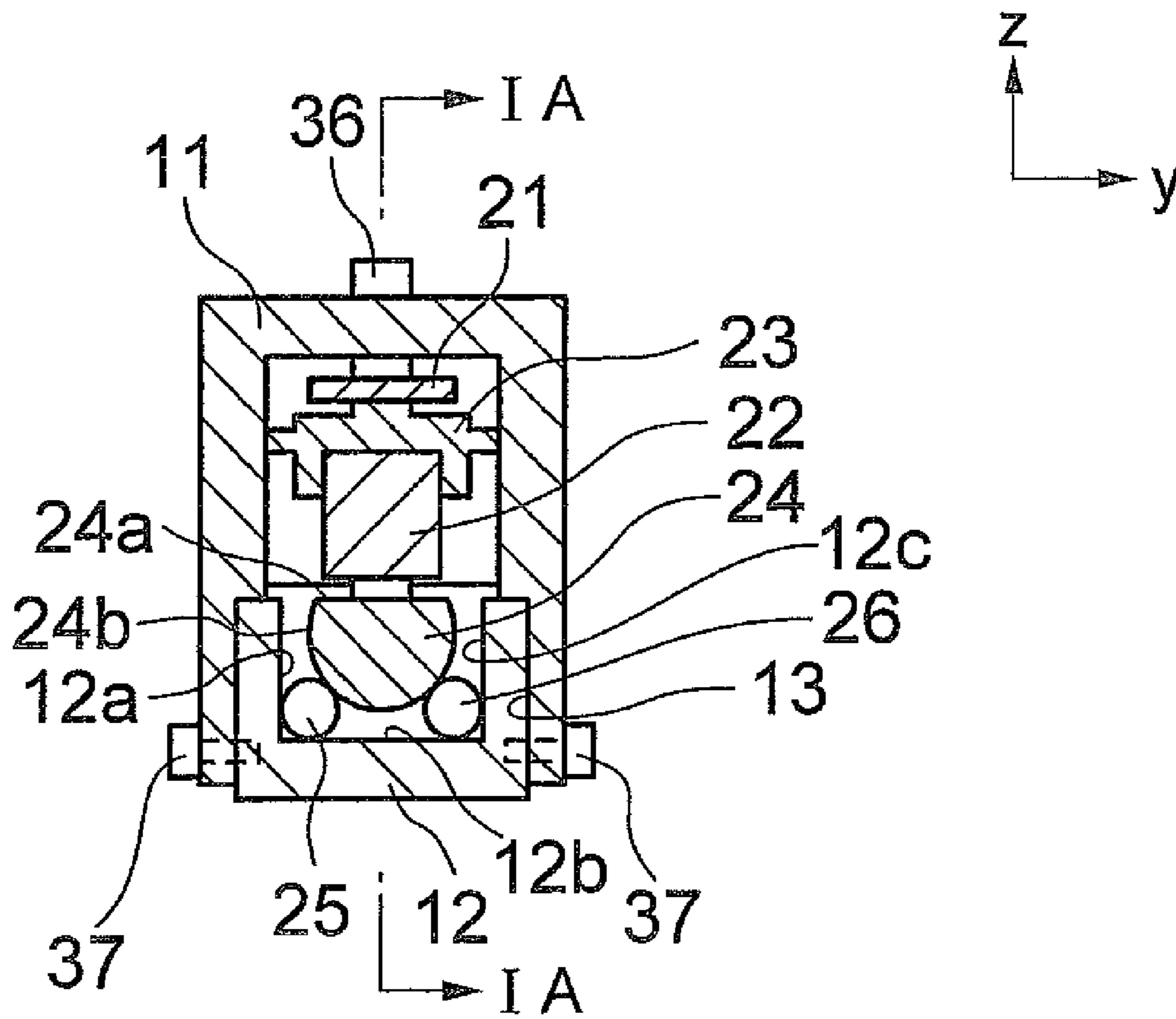


FIG. 1A



# FIG. 1B



10

FIG.2

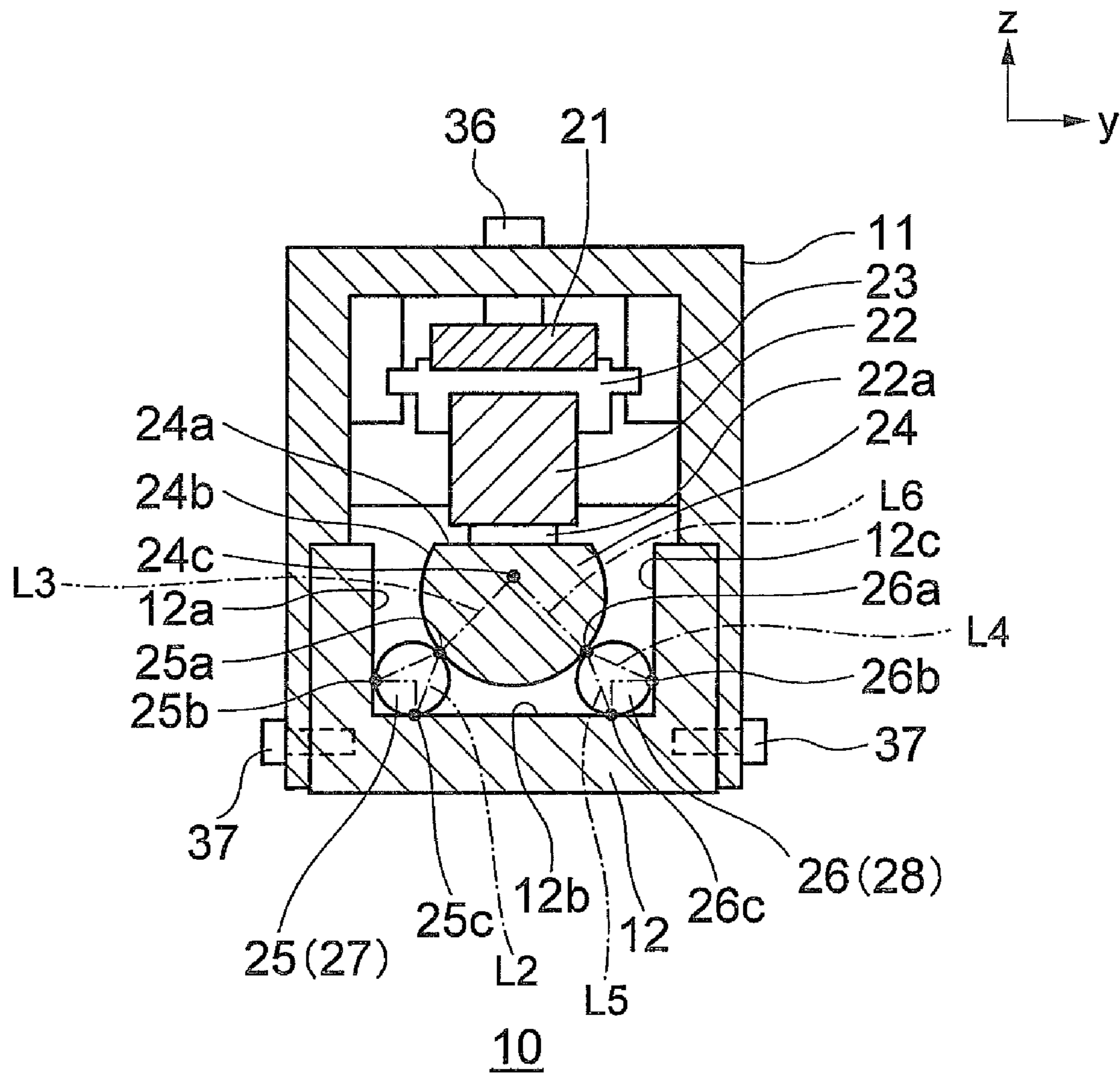


FIG. 3

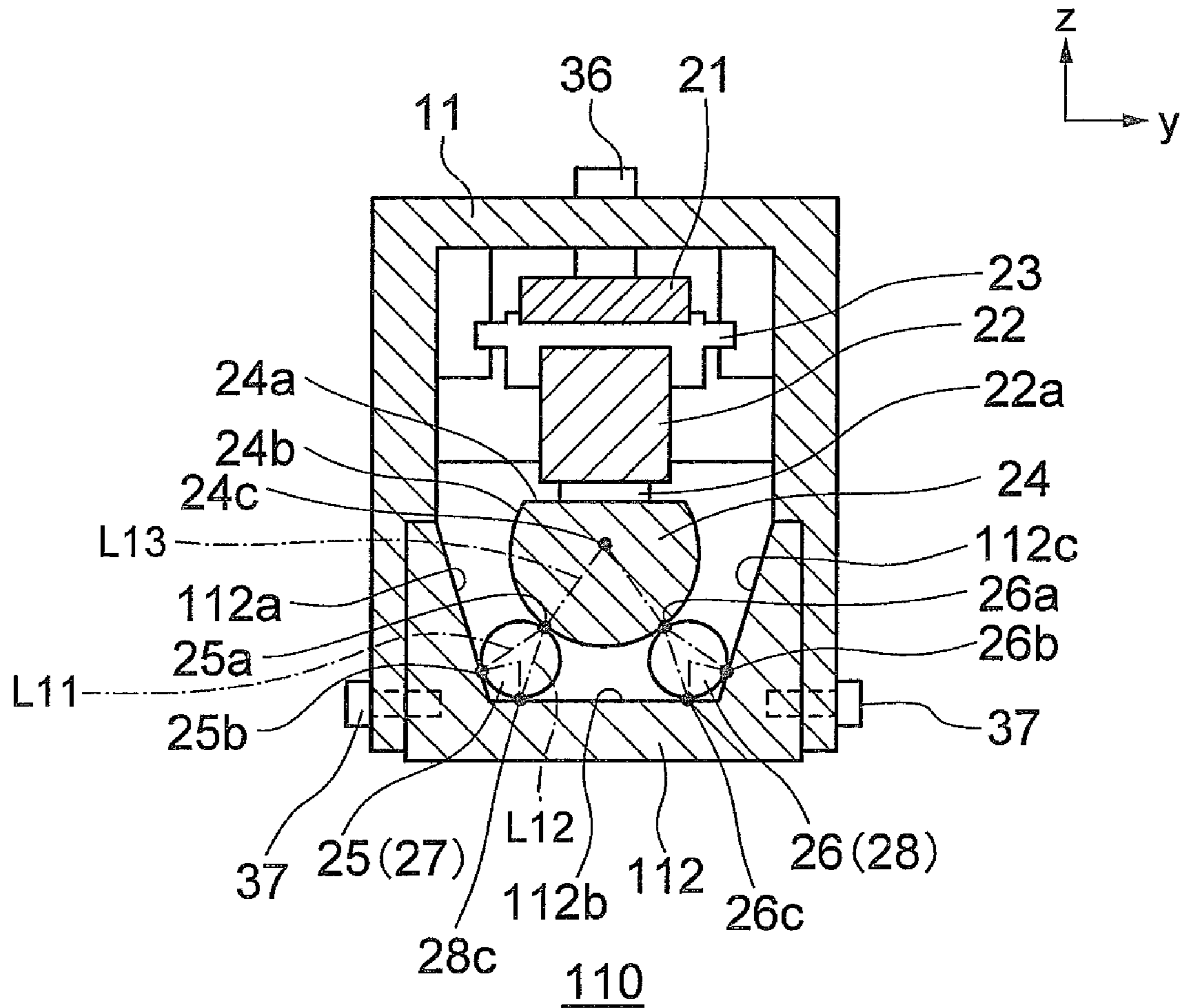


FIG. 4

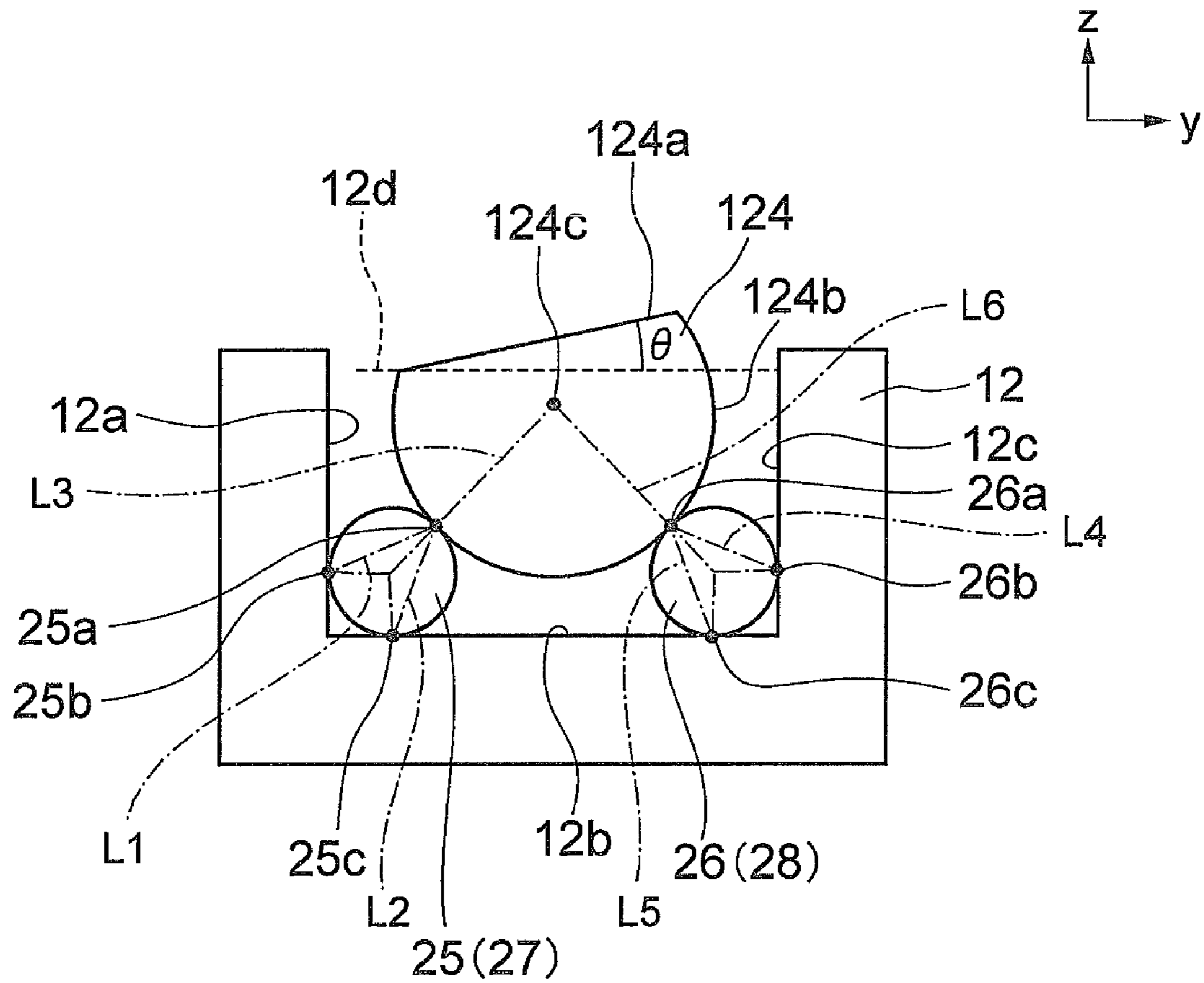


FIG. 5

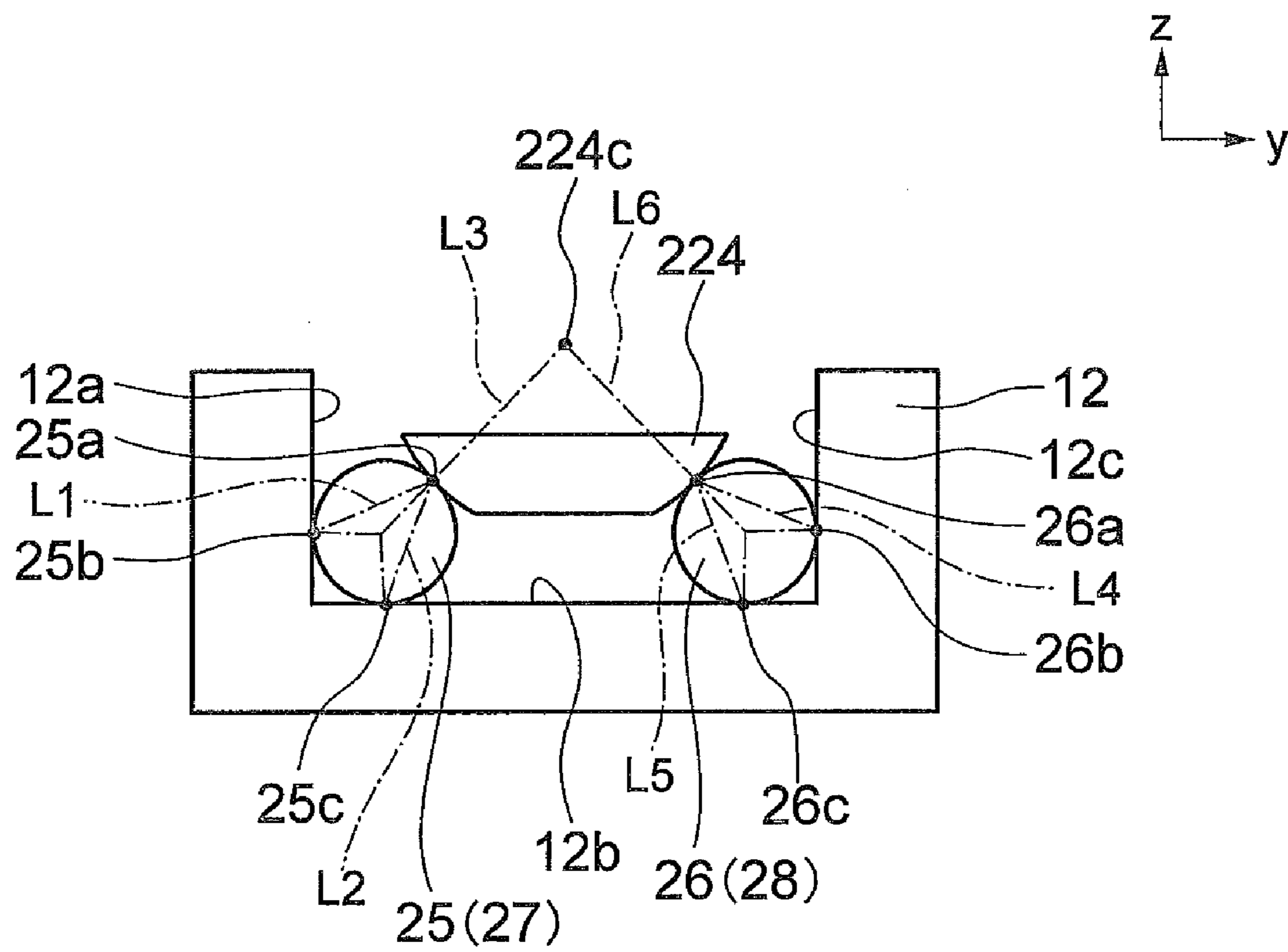


FIG. 6

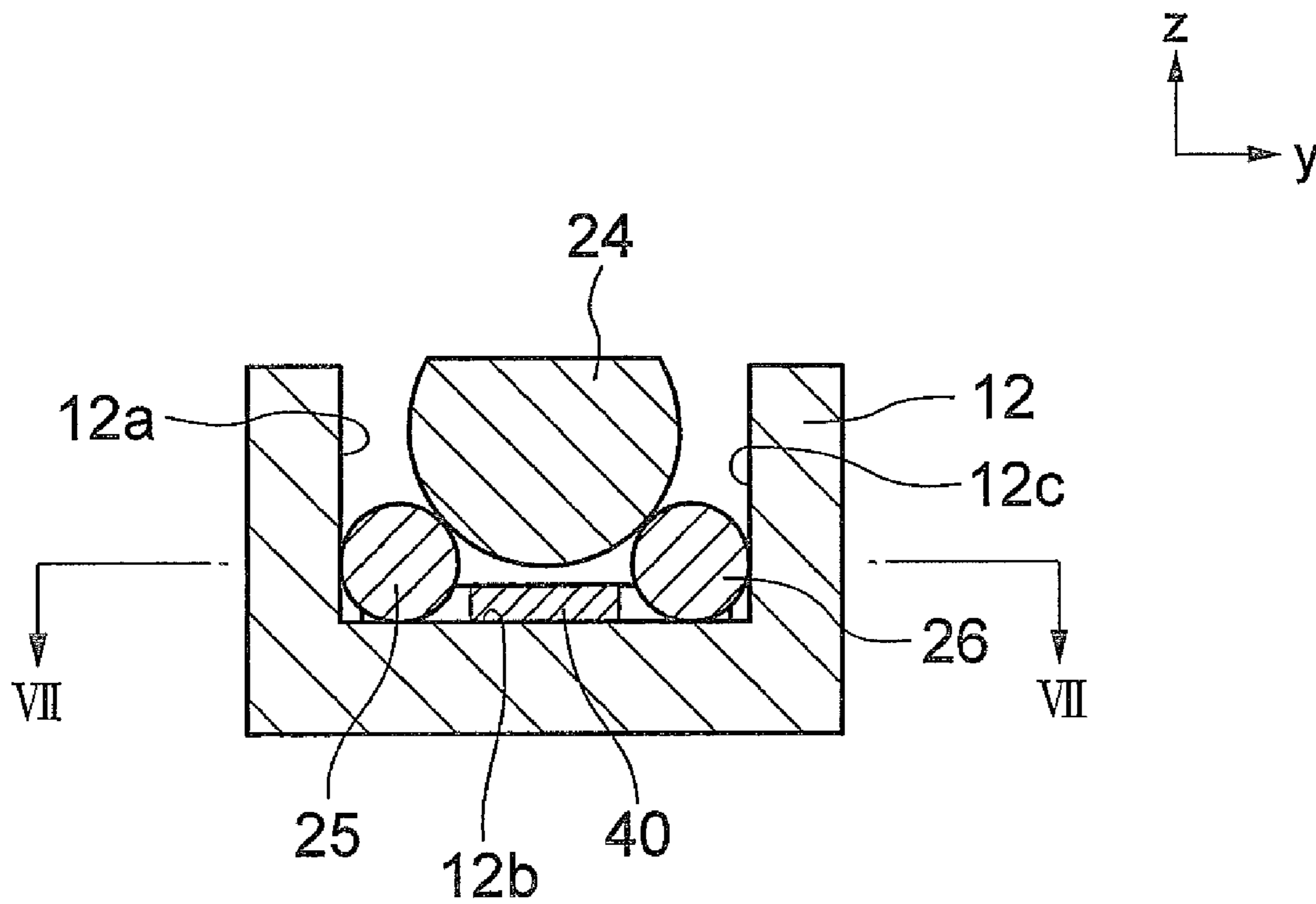




FIG. 7

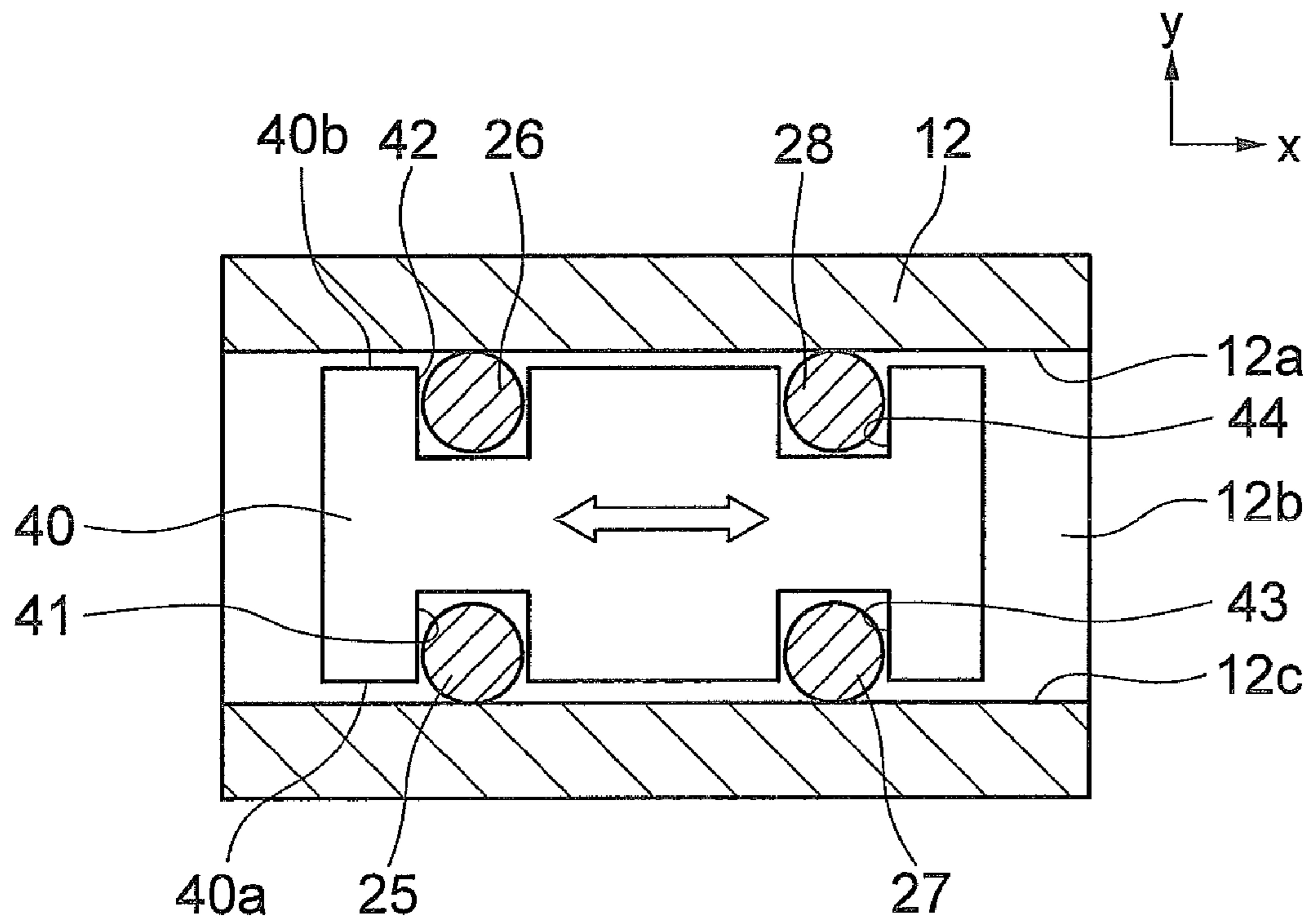


FIG. 8

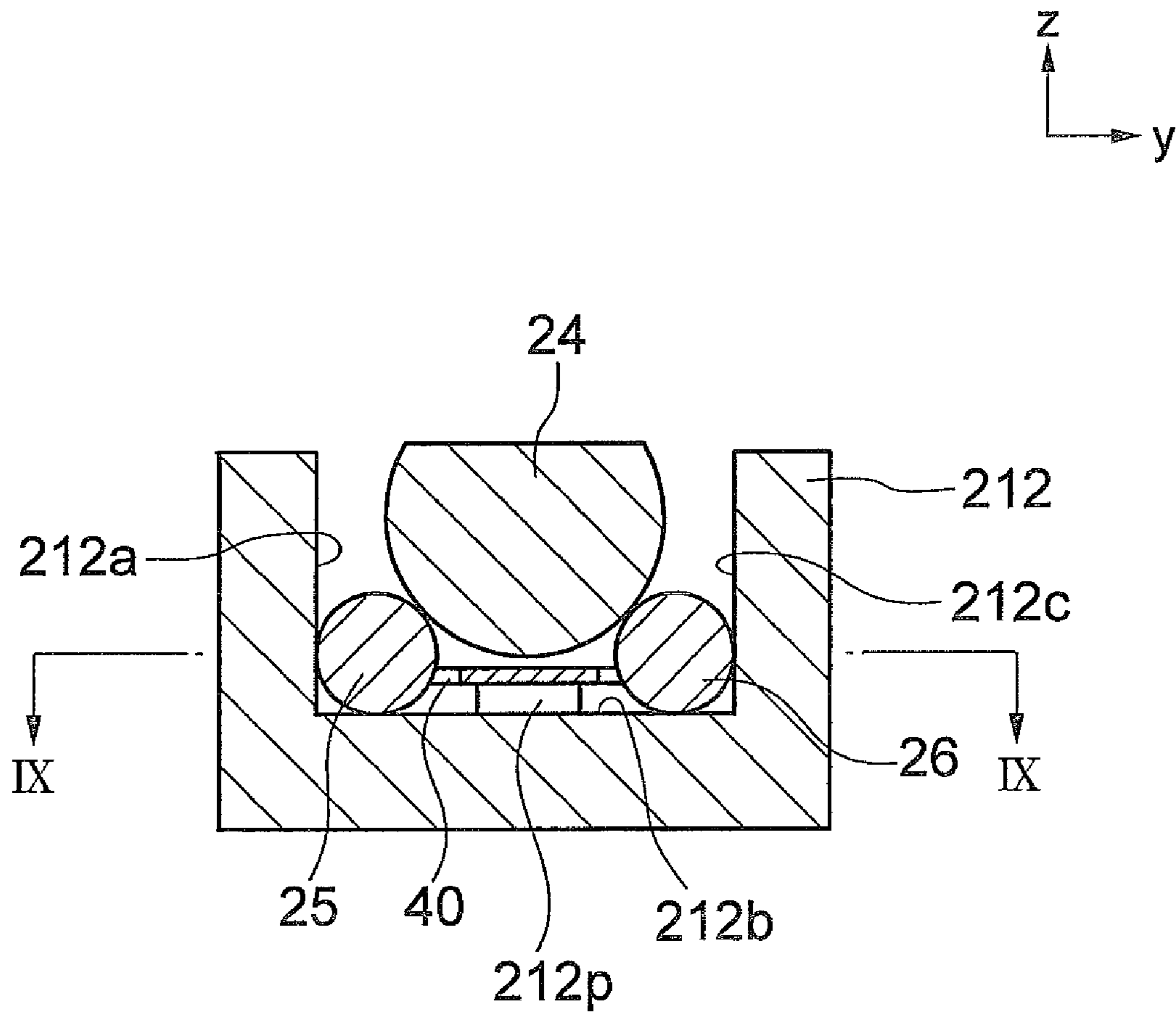


FIG. 9

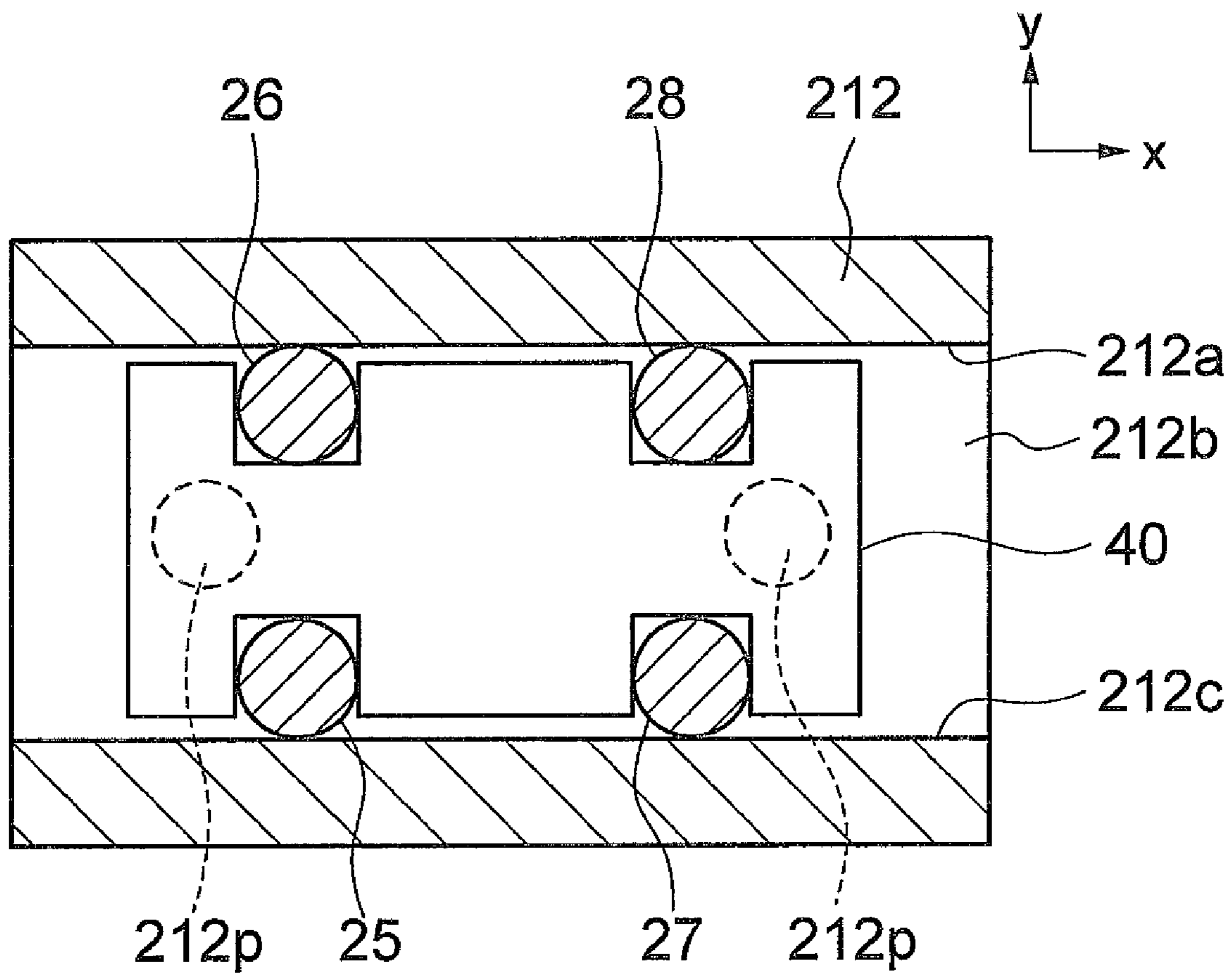


FIG. 10

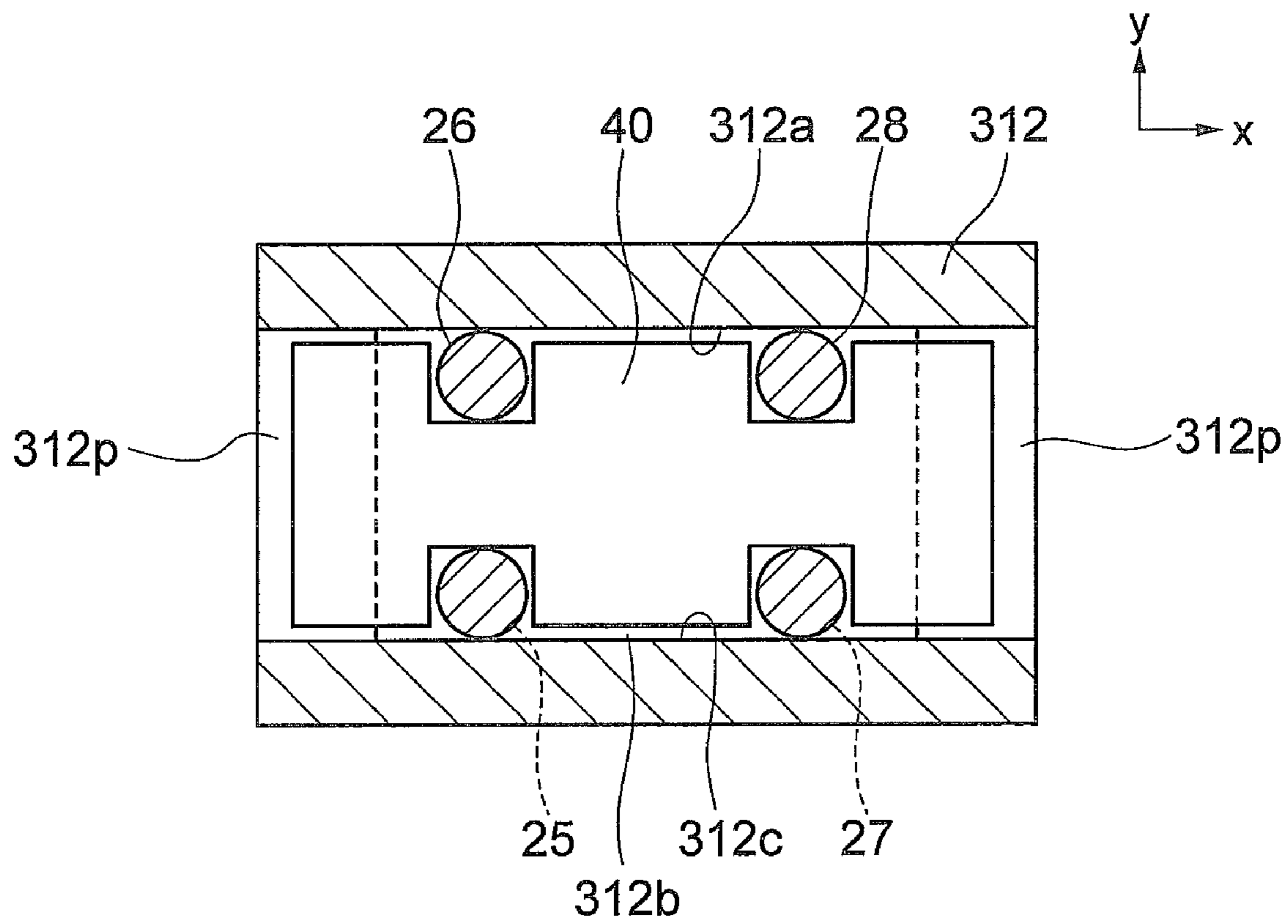
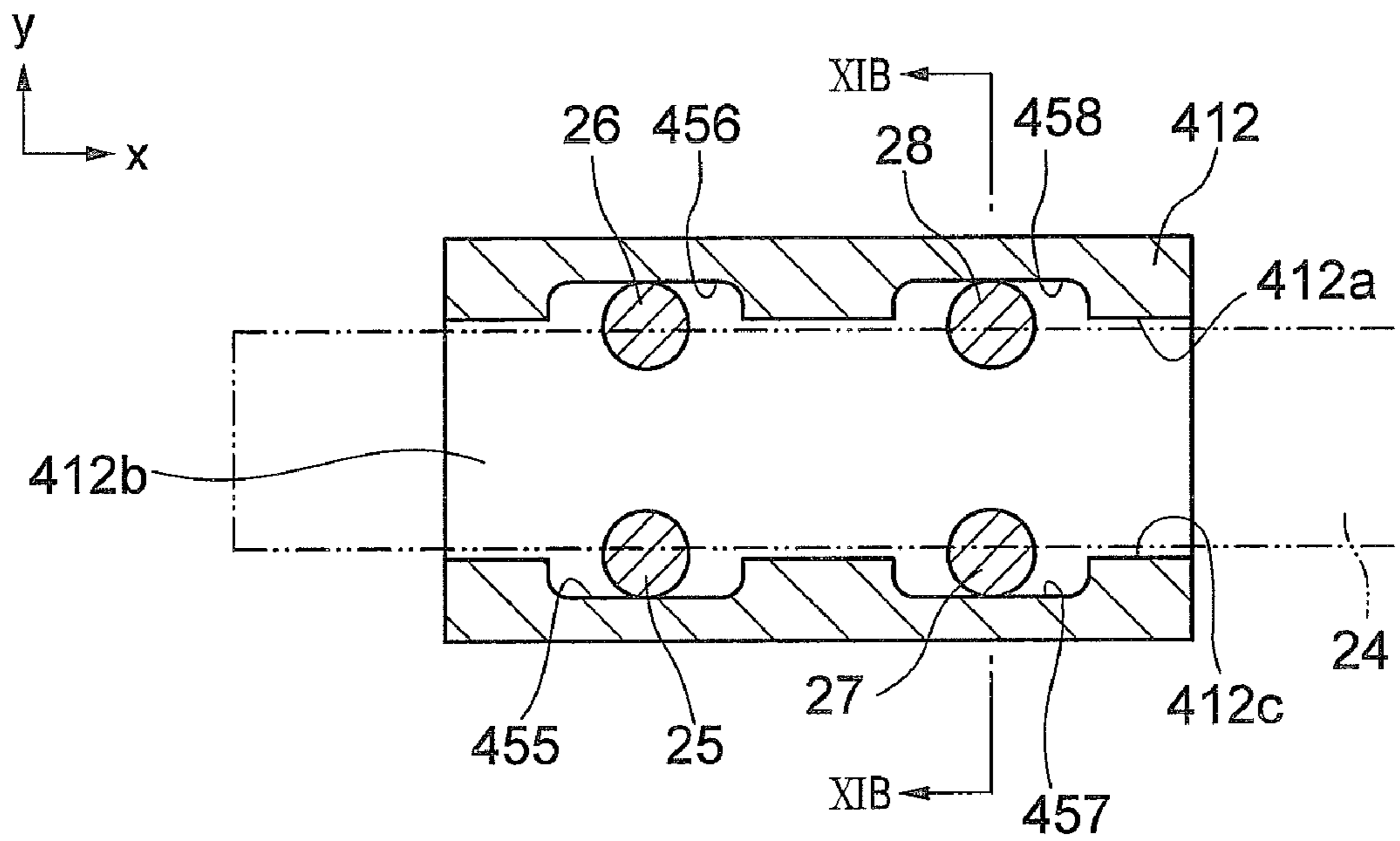


FIG. 11A



# FIG. 11B

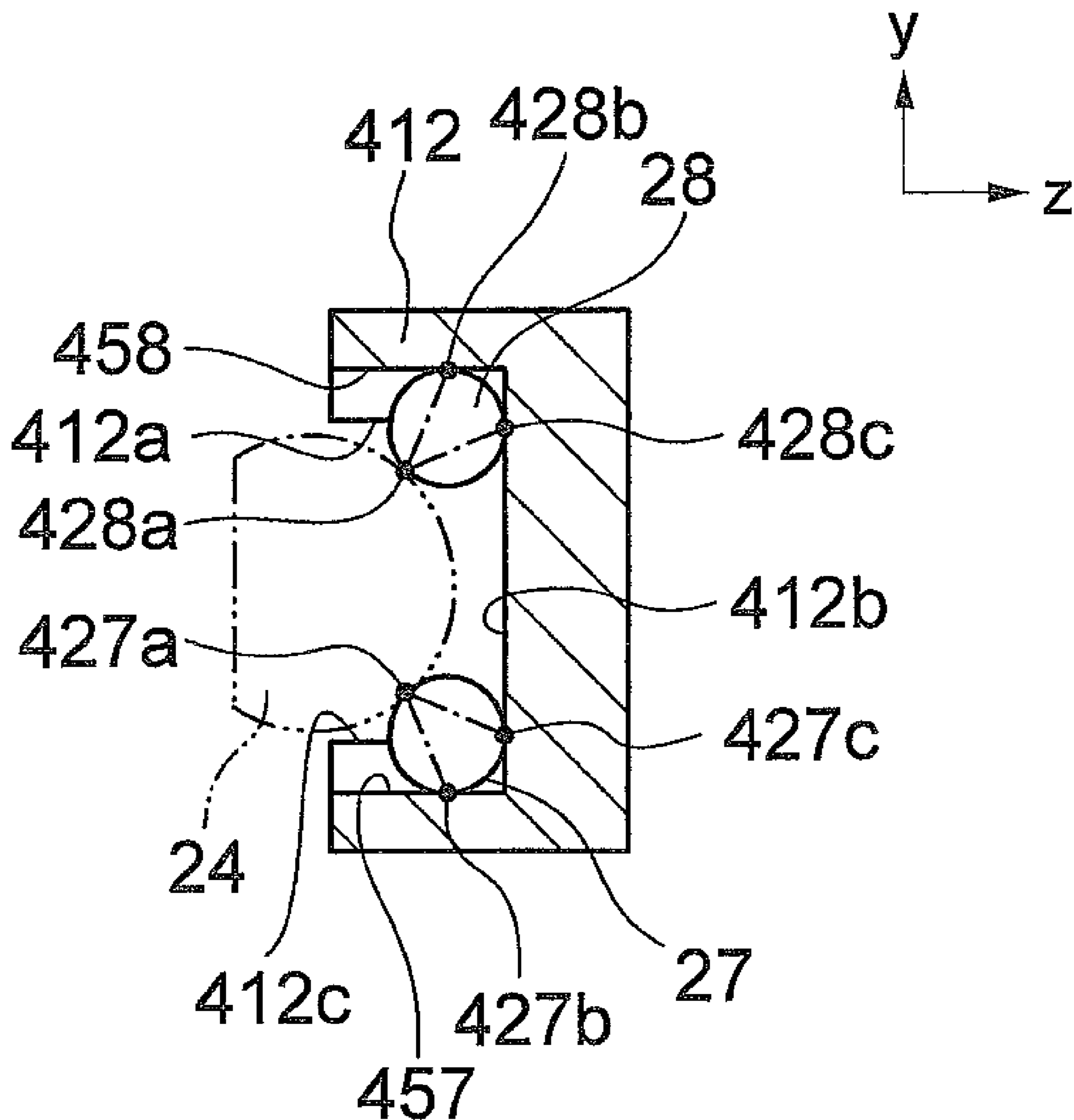
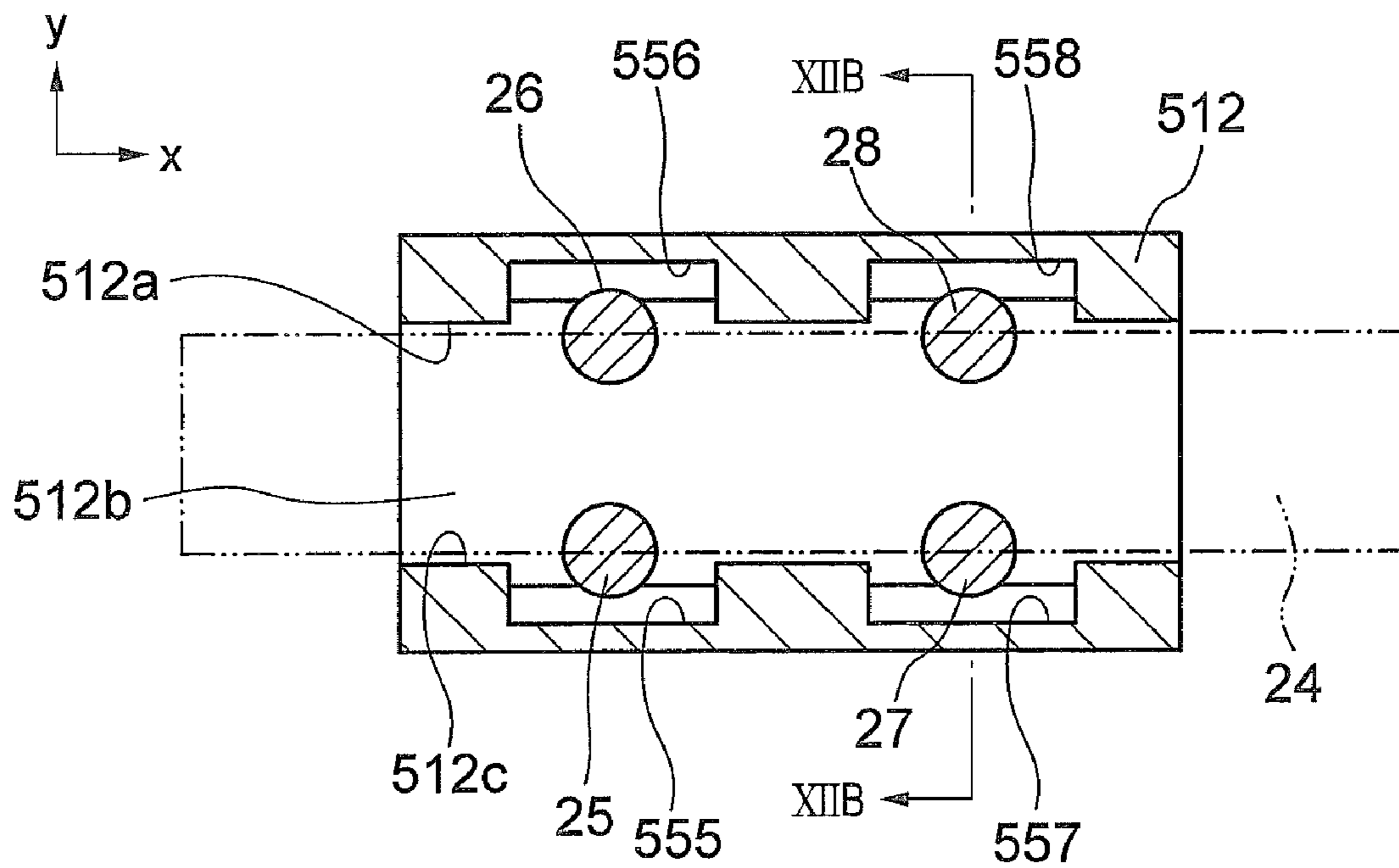


FIG. 12A



# FIG. 12B

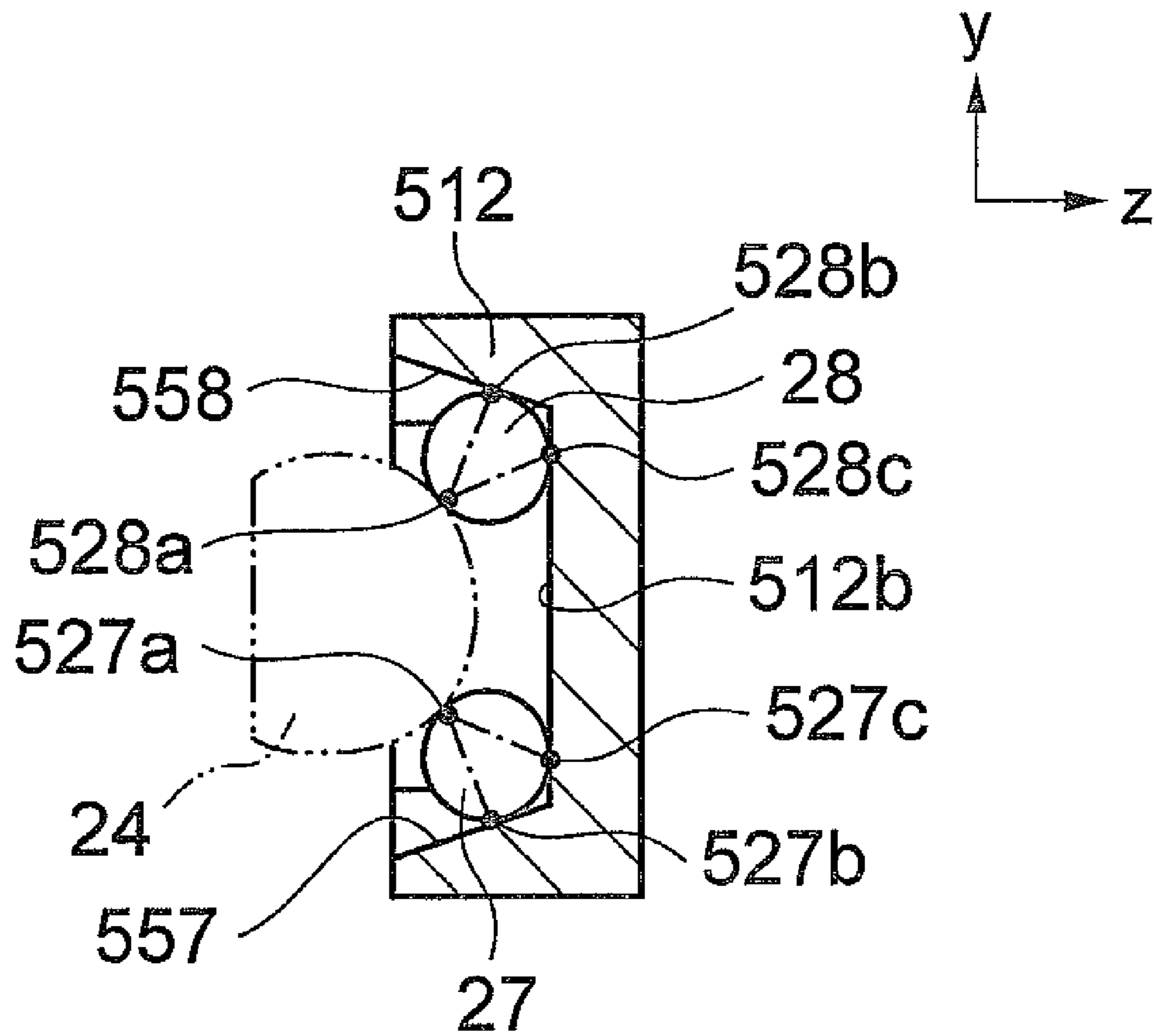




FIG. 13

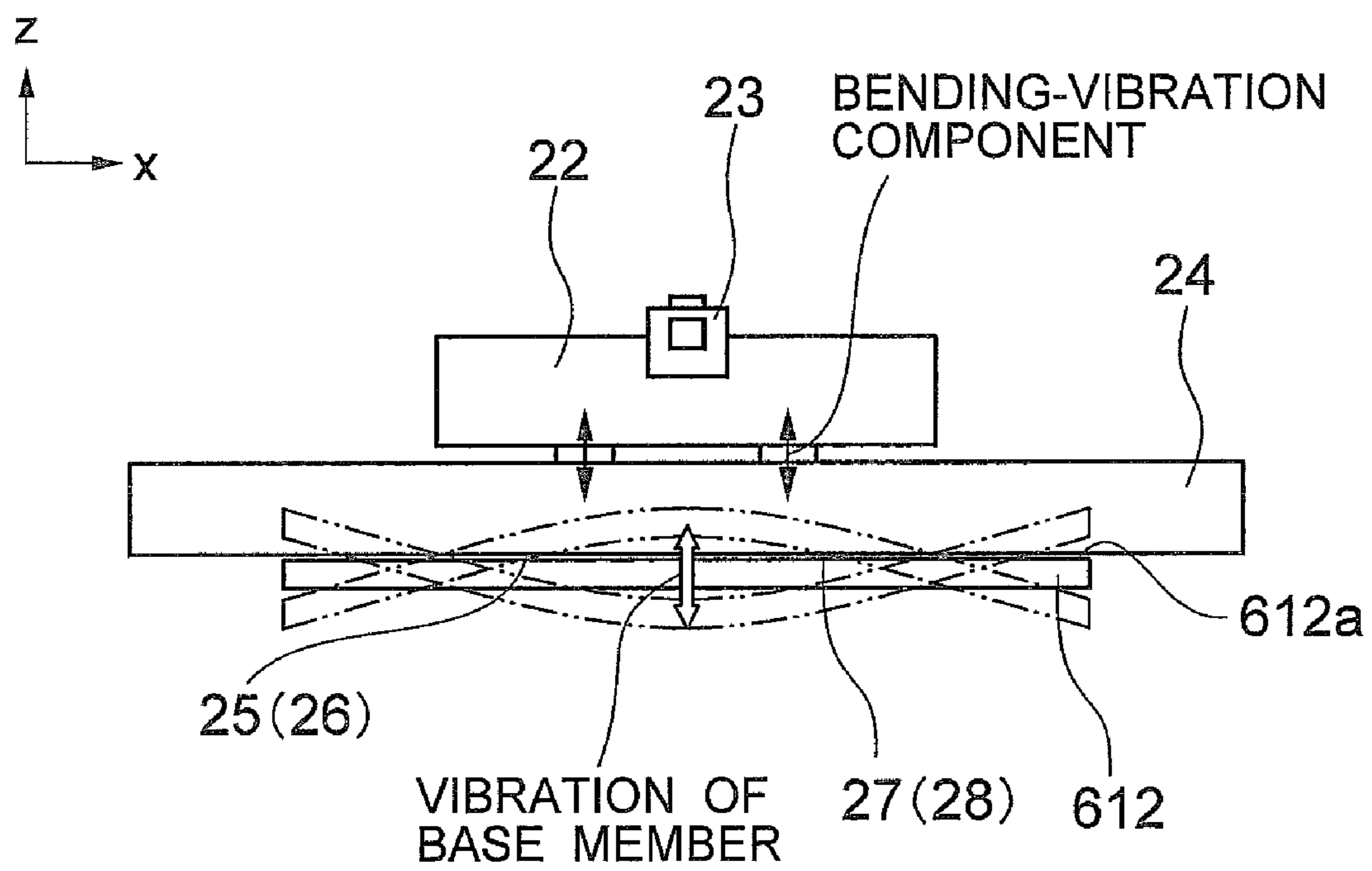


FIG. 14

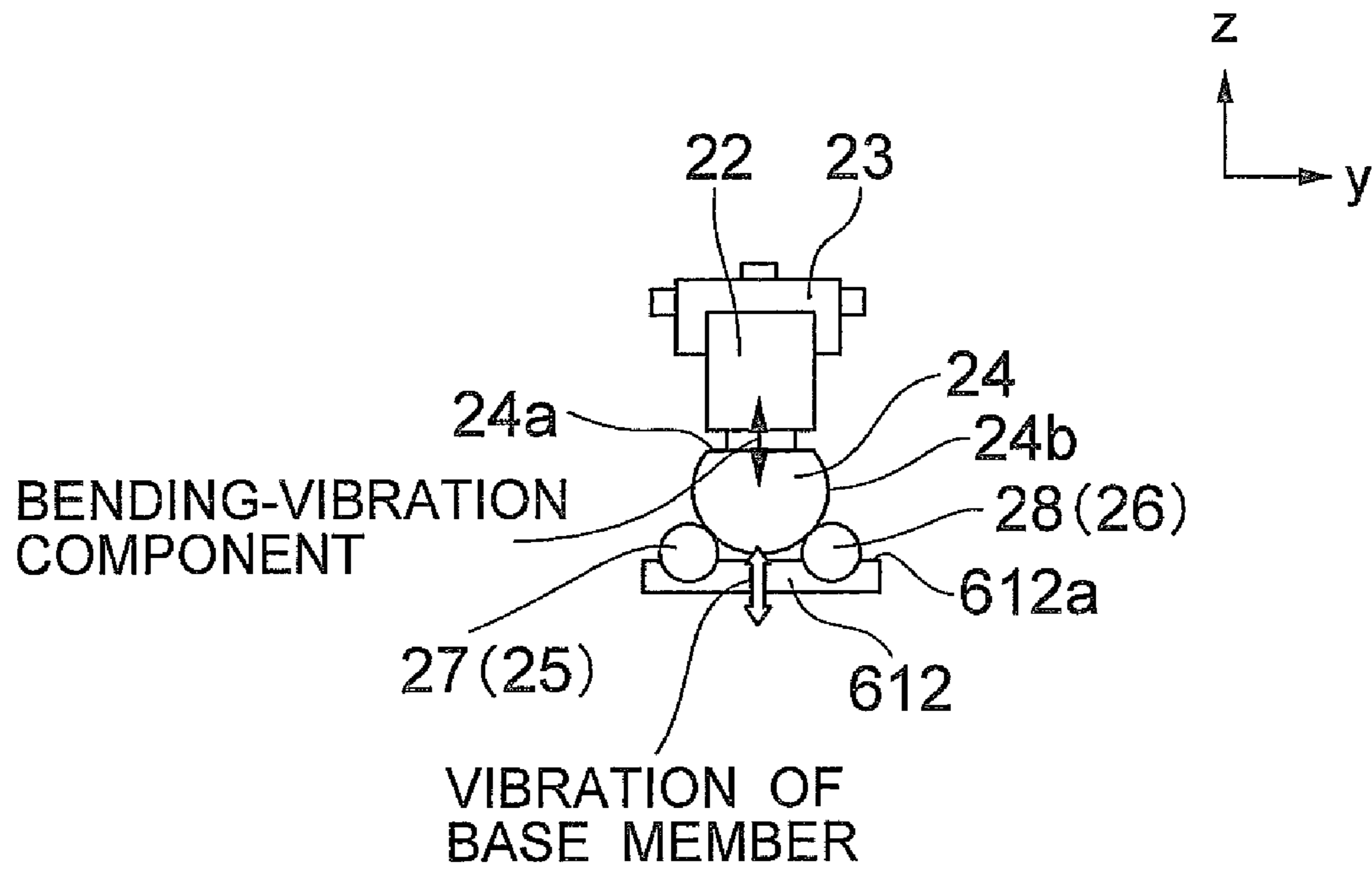


FIG. 15

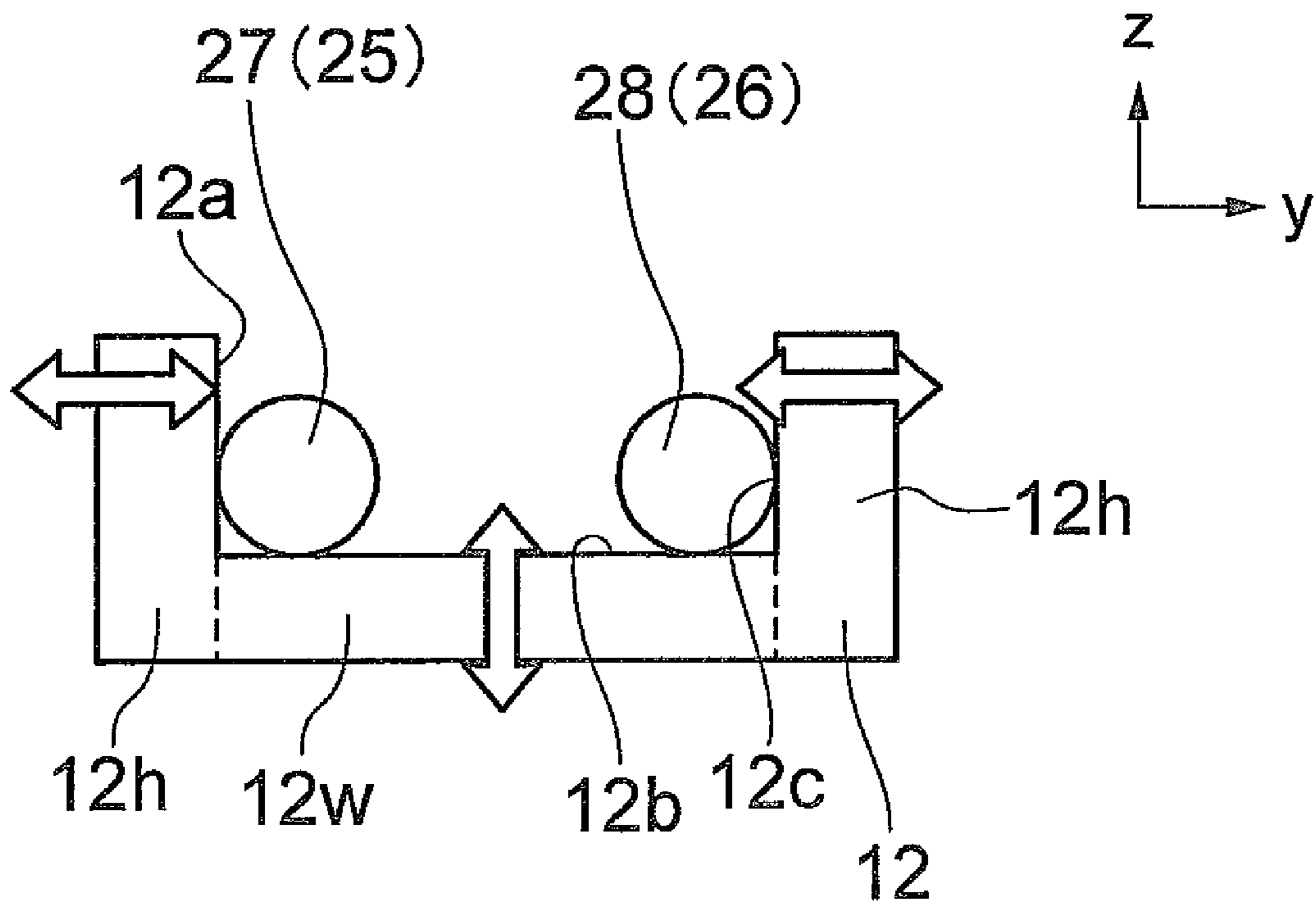


FIG. 16

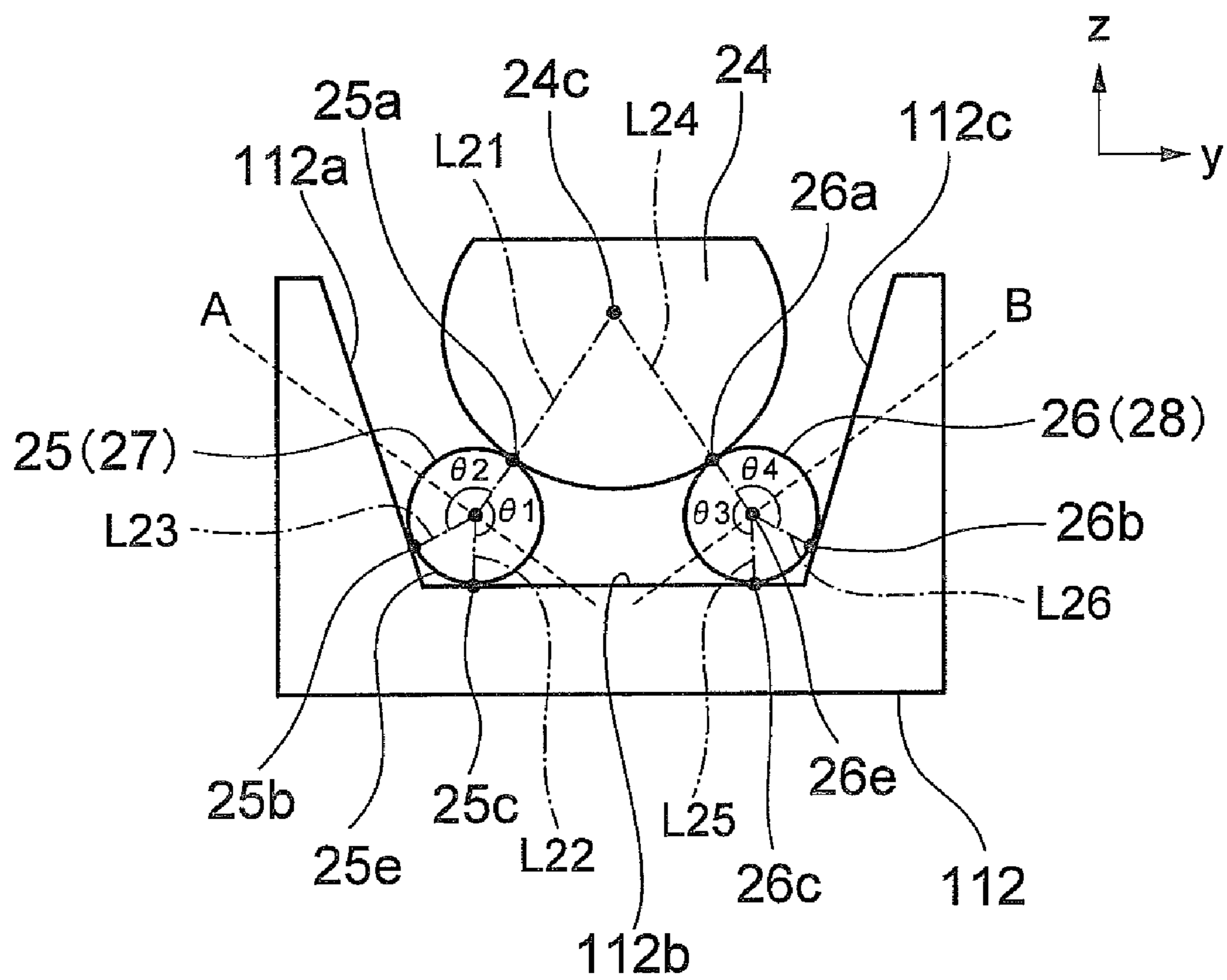


FIG. 17

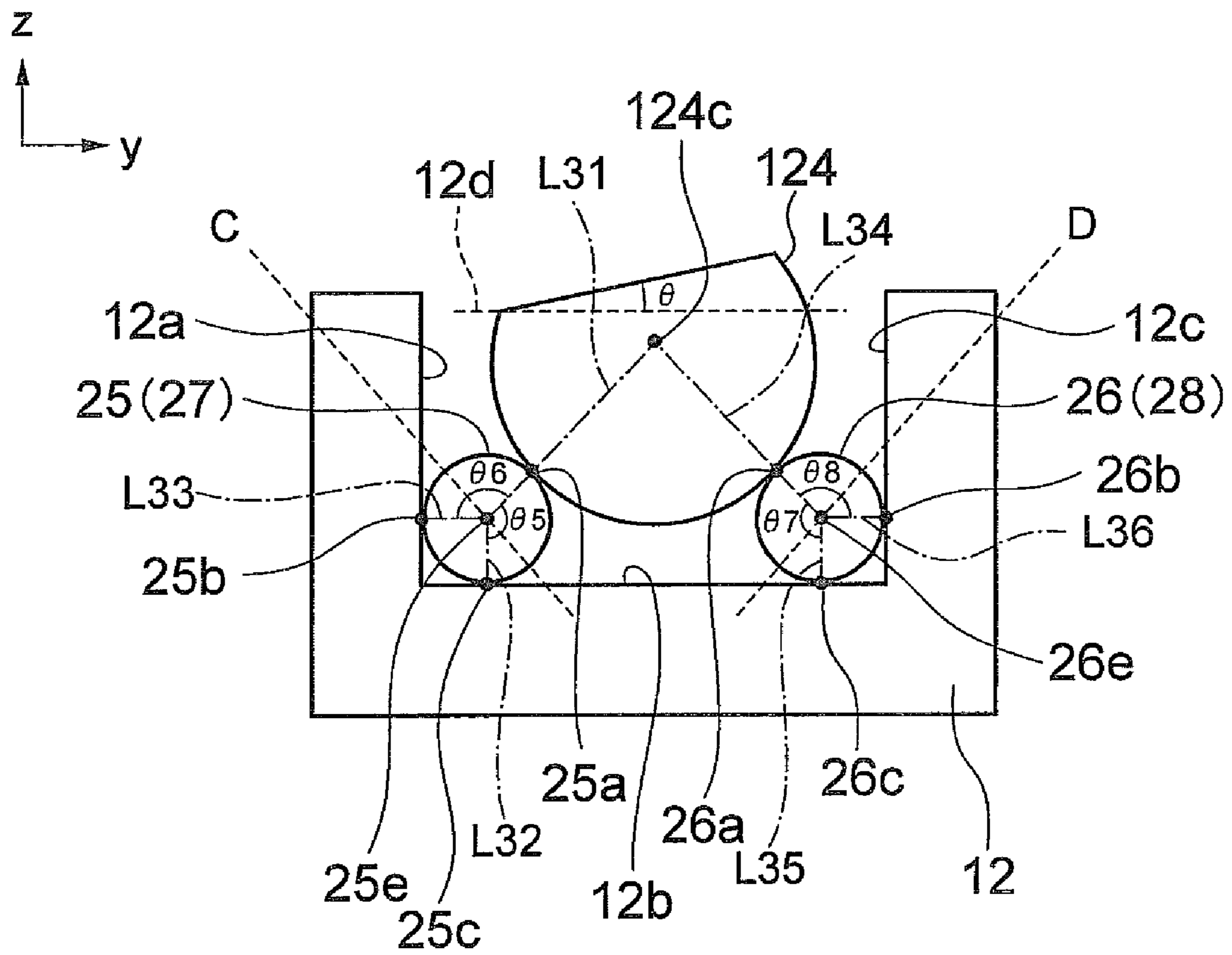


FIG. 18A

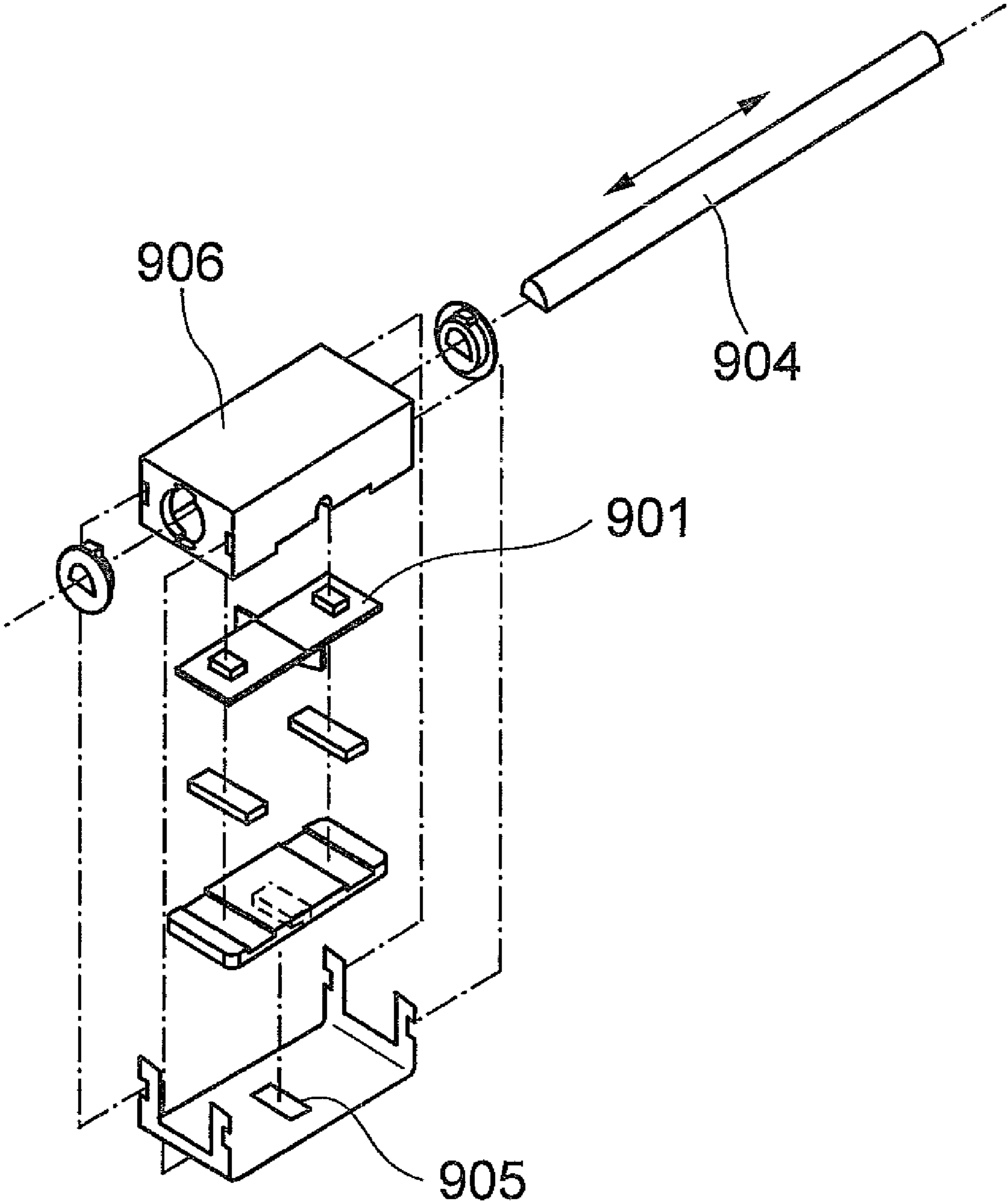
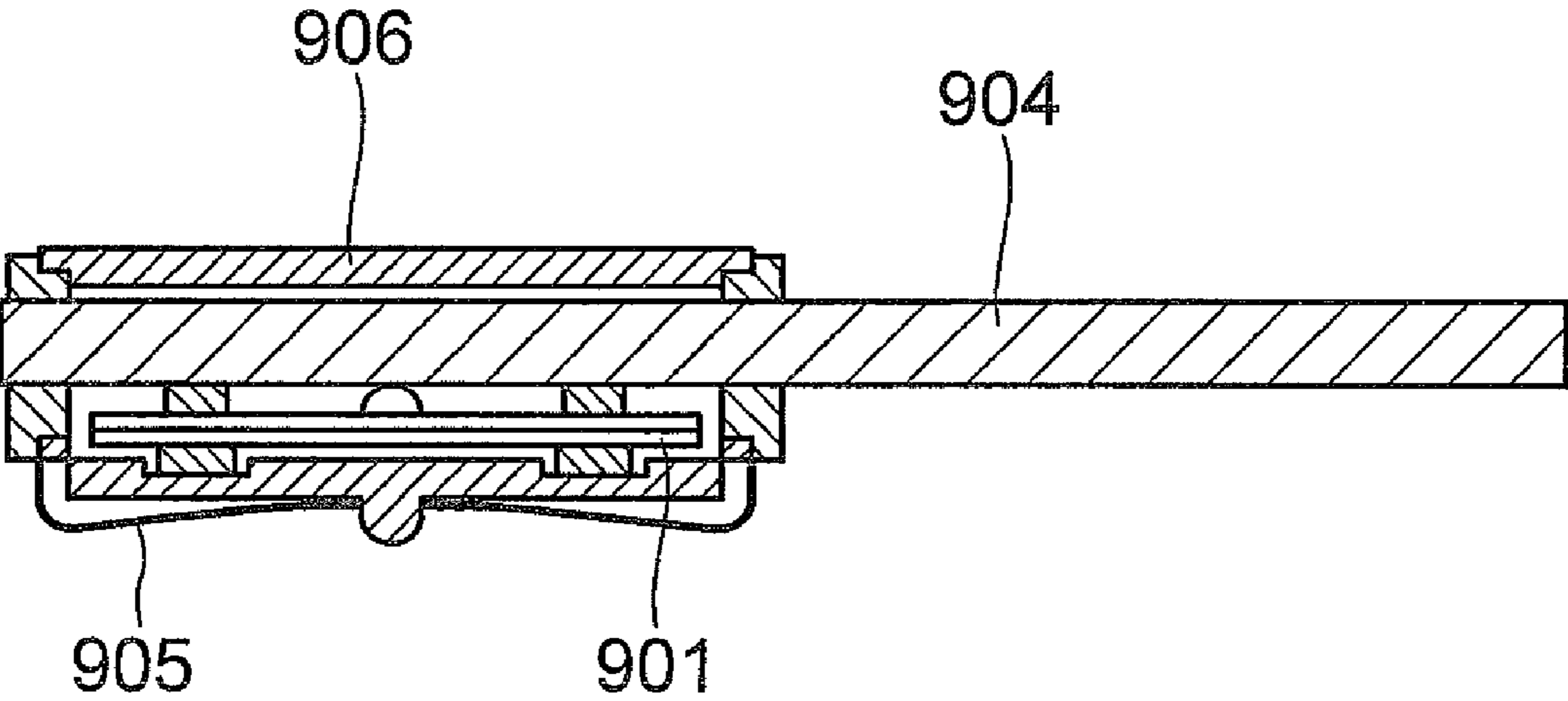


FIG. 18B



## 1

## LINEAR DRIVE ULTRASONIC MOTOR

CROSS-REFERENCE TO RELATED  
APPLICATIONS

The present application is based upon and claims the benefit of priority from prior Japanese Patent Application No. 2008-114222 filed on Apr. 24, 2008; the entire contents of which is incorporated herein by reference.

## TECHNICAL FIELD

The present invention relates to a linear drive ultrasonic motor.

## BACKGROUND ART

As a conventional linear drive ultrasonic motor, a vibration apparatus described in Patent Literature 1 can be cited as an example (FIG. 18A and FIG. 18B). Here, FIGS. 18A and 18B are diagrams showing a structure of a conventional linear drive ultrasonic motor, where, FIG. 18A is an exploded perspective view and FIG. 18B is a vertical cross-sectional view.

The vibration apparatus shown in FIG. 18A and FIG. 18B includes a case 906 which accommodates a vibrating body 901, a mobile object 904 which passes through the case 906 and makes a contact with the vibrating body 901, and a pressing spring 905 which generates thrust (bias) which brings the mobile object 904 and the vibrating body 901 in a pressurized contact. The pressing spring 905 is installed at an outer side of the case 906. An opening portion is formed in a side of the case 906, facing the vibrating body 901, and the thrust of the pressing spring 905 acts on the vibrating body 901 through the opening portion. In other words, this vibration apparatus has a structure in which, the pressing spring 905 is installed on the outer side of the case 906 while covering the opening portion of the case 906, and a deformed portion (a flat surface portion covering the opening portion) of the pressing spring 905 which generates the thrust, is exposed.

As in the vibration apparatus described in Patent Literature 1, making a unit structure in which, main structural components are packaged, is effective from a point of generality and stabilizing of characteristics. However, in an ultrasonic motor apparatus, small-sizing, and high output have been sought. Patent Literature: Japanese Patent No. 3524248 Specification

## DISCLOSURE OF THE INVENTION

## Problems to be Solved by the Invention

However, in the vibration apparatus described in Patent Literature 1, the structure is such that, the mobile object 904 is guided in a direction of movement and around an axis of the mobile object 904 by a sliding bearing which is provided in a hole of the case 906. In this structure, since the mobile object is pressed against the case 906 by the pressing spring 905, a contact pressure of a contact portion with the sliding bearing provided in the hole of the case 906 is high, and a sliding friction when the mobile object 904 moves is substantial. Therefore, a sliding resistance becomes substantial, and becomes a cause of a decline in output. Moreover, since the mobile object 904 vibrates by the vibrating body 901, there has been a problem that wearing out of a portion subjected to sliding friction accelerates. When the bearing such as a thrust bearing which is normally used for this portion, it leads to an increase in the size of the apparatus. Moreover, in the vibra-

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tion apparatus of the Patent Literature 1, providing a guide mechanism which guides the mobile object 904 at an interior of the case 906 is difficult from a view point of small-sizing. Furthermore, it is also difficult to form a guiding mechanism having a small frictional resistance while maintaining the small-sizing, at the interior of the case.

The present invention has been made in view of the above-mentioned circumstances, and an object of the present invention is to provide a linear drive ultrasonic motor of which, a size can be made small, and in which, it is possible to guide assuredly while reducing a transfer resistance and the frictional resistance of a driven member.

## Means for Solving the Problems

To solve the abovementioned problems and to achieve the object, a linear drive ultrasonic motor according to the present invention includes at least

an ultrasonic vibrator having a piezoelectric element,  
a driven member which is driven by a frictional force between the driven member and the ultrasonic vibrator,  
a pressing member which presses the ultrasonic vibrator such that, a frictional force is generated between the ultrasonic vibrator and the driven member,  
a rolling member having a spherical shape, which makes a contact with the driven member, and  
a base member which movably supports the driven member via the rolling member, and  
the rolling member makes a contact with the driven member at a first contact point, and makes a contact with the base member at two second contact points, and  
lengths of straight lines connecting the first contact point and two second contact points are substantially same.

In the linear drive ultrasonic motor according to the present invention, it is preferable that the driven member has a curved surface within a range in which, at least the first contact point exists.

In the linear drive ultrasonic motor according to the present invention, it is preferable that the rolling member is disposed at a position which is not exactly under the driven member.

In the linear drive ultrasonic motor according to the present invention, it is desirable that the linear drive ultrasonic motor includes a guiding member which includes a plurality of rolling members, and which guides the rolling members in a direction in which the driven member is driven, while maintaining a relative positional relationship of the rolling members.

In the linear drive ultrasonic motor according to the present invention, there can be provided a protruding portion which is lower than a radius of the rolling member, at a bottom surface of the base member.

In the linear drive ultrasonic motor according to the present invention, it is preferable to provide to the base member, a base guiding mechanism which includes a plurality of rolling members, and which guides the rolling members in a direction in which, the driven member is driven, while maintaining a relative positional relationship of the rolling members.

In the linear drive ultrasonic motor according to the present invention, it is preferable that the base member has a flat surface corresponding independently to each of the two second contact points, toward the rolling member.

In the linear drive ultrasonic motor, it is preferable that in the base member, an angle made by adjacent flat surfaces is a right angle.



In the linear drive ultrasonic motor, it is preferable that in the base member, an angle made by adjacent flat surfaces is an obtuse angle.

#### Effect of the Invention

A linear drive ultrasonic motor according to the present invention shows an effect that it has a structure in which, it is possible to reduce a transfer resistance and a frictional resistance of a driven member while guiding the driven member assuredly, and furthermore, it is possible to maintain and accelerate small-sizing.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a diagram showing a structure of an ultrasonic motor according to a first embodiment of the present invention, and is a cross-sectional view taken along a line IA-IA in FIG. 1B;

FIG. 1B is a diagram showing a structure of the ultrasonic motor according to the first embodiment of the present invention, and is a cross-sectional view orthogonal to a center in a longitudinal direction of a case member;

FIG. 2 is a cross-sectional view orthogonal to the center in the longitudinal direction of the case member of the ultrasonic motor according to the first embodiment of the present invention;

FIG. 3 is a cross-sectional view orthogonal to a center in a longitudinal direction of a case member of an ultrasonic motor according to a first modified embodiment of the first embodiment;

FIG. 4 is a cross-sectional view orthogonal to a center in a longitudinal direction of a base member of an ultrasonic motor according to a second modified embodiment of the first embodiment;

FIG. 5 is a cross-sectional view orthogonal to a center in a longitudinal direction of a base member of an ultrasonic motor according to a third modified embodiment of the first embodiment;

FIG. 6 is cross-sectional view which is orthogonal to a longitudinal direction of a base member of an ultrasonic motor according to a second embodiment of the present invention, and which passes through a rolling member;

FIG. 7 is a cross-sectional view taken along a line VII-VII in FIG. 6;

FIG. 8 is a cross-sectional view which is orthogonal to a longitudinal direction of a base member of an ultrasonic motor according to a third embodiment of the present invention, and which passes through a rolling member;

FIG. 9 is a cross-sectional view taken along a line IX-IX in FIG. 8;

FIG. 10 is cross-sectional view showing a positional relationship of the base member, a guiding member, a protruding portion, and the rolling member according to the third embodiment;

FIG. 11A is a cross-sectional view showing a positional relationship of a driven member, a base member, and a rolling member according to a fourth embodiment;

FIG. 11B is a cross-sectional view showing a positional relationship of the driven member, the base member, and the rolling member according to the fourth embodiment, and is a cross-sectional view taken along a line XIB-XIB in FIG. 11A;

FIG. 12A is a cross-sectional view showing a positional relationship of a driven member, a base member, and a rolling member according to a modified embodiment of the fourth embodiment;

FIG. 12B is a cross-sectional view showing a positional relationship of the driven member, the base member, and the rolling member according to the modified embodiment of the fourth embodiment, and is a cross-sectional view taken along a line XIIB-XIIB in FIG. 11A;

FIG. 13 is a side view showing a structure of an ultrasonic motor according to an example for comparison;

FIG. 14 is a front view showing a structure of the ultrasonic motor according to the example for comparison;

FIG. 15 is a front view showing a positional relationship of a base member and rolling members according to the first embodiment and the modified embodiments thereof; and

FIG. 16 is a cross-sectional view orthogonal to a center in a longitudinal direction of a base member of the ultrasonic motor according to the first modified embodiment of the first embodiment;

FIG. 17 is a cross-sectional view orthogonal to the center in the longitudinal direction of the base member of the ultrasonic motor according to the second modified embodiment of the first embodiment;

FIG. 18A is a diagram showing a structure of a conventional linear drive ultrasonic motor, and is an exploded perspective view; and

FIG. 18B is a diagram showing the structure of the conventional linear drive ultrasonic motor, and is a vertical cross-sectional view.

#### DESCRIPTION OF REFERENCE NUMERALS

- 10 ultrasonic motor (linear drive ultrasonic motor)
- 11 case member
- 11*h* screw hole
- 12 base member
- 12*a*, 12*c* side surfaces
- 12*b* bottom surface
- 13 opening portion
- 16 accommodating recess
- 21 pressing member
- 21*a*, 21*b* end portions
- 21*c* central portion
- 22 vibrator (ultrasonic vibrator)
- 22*a* stator
- 23 supporting member
- 24 driven member
- 24*a* flat surface
- 24*b* curved surface
- 25, 26, 27, 28 rolling members
- 25*a* contact point (first contact point)
- 25*b*, 25*c* contact points (second contact points)
- 26*a* contact point (first contact point)
- 26*b*, 26*c* contact points (second contact points)
- 36 pressing adjustment screw (pressurizing portion)
- 40 guiding member
- 41, 42, 43, 44 notches
- 124 driven member
- 124*a* flat surface portion
- 124*b* curved surface portion
- 212 base member
- 212*a*, 212*c* side surfaces
- 212*b* bottom surface
- 224 driven member
- 224*a* flat surface portion
- 224*b* curved surface portion
- 212*p* protruding portion
- 412 base member
- 412*a*, 412*c* side surfaces
- 412*b* bottom surface

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427a contact point (first contact point)  
 427b, 427c contact points (second contact points)  
 428a contact point (first contact point)  
 428b, 428c contact points (second contact points)  
 455, 456, 457, 458 notches (base guiding mechanisms)  
 512 base member  
 512a, 512c side surfaces  
 512b bottom surface  
 527a contact point (first contact point)  
 527b, 527c contact points (second contact points)  
 528a contact point (first contact point)  
 528b, 528c contact points (second contact points)  
 555, 556, 557, 558 notches (base guiding mechanisms)

BEST MODE FOR CARRYING OUT THE  
 INVENTION

Embodiments of an ultrasonic motor 10 (a linear drive ultrasonic motor) according to the present invention will be described below in detail by referring to the accompanying diagrams. However, the present invention is not restricted to the embodiments described below.

First Embodiment

The ultrasonic motor 10 (the linear drive ultrasonic motor) according to a first embodiment and modified embodiments thereof will be described below while referring to diagrams from FIG. 1A to FIG. 5. Here, FIG. 1A and FIG. 1B are diagrams showing a structure of the ultrasonic motor 10, where, FIG. 1A is a cross-sectional view taken along a line IA-IA in FIG. 1B, and FIG. 1B is a cross-sectional view orthogonal to a center in a longitudinal direction (x-direction) of a case member 11. As shown in FIG. 1A and FIG. 1B, the ultrasonic motor 10 includes a vibrator 22 as an ultrasonic vibrator, a driven member 24, a pressing member 21, rolling members 25, 26, 27, and 28, the case member 11, and a base member 12. Each member will be described below in detail.

Both the vibrator 22 and the case member 11 have a substantially rectangular parallelepiped outer shape, and an accommodating recess 16 is formed at an interior of the case member 11, which reaches up to an outside from an opening portion 13 which is closed by disposing the base member 12. The vibrator 22 and the pressing member 21 are accommodated in order from a side of the opening portion 13 in a direction of height (z-direction in FIG. 1A) of the ultrasonic motor 10, inside the accommodating recess 16. The pressing member 21 is a plate spring in the form of a long plate, and is disposed such that a longitudinal direction thereof is along a longitudinal direction (x-direction in FIG. 1A) of the ultrasonic motor 10 and the case member 11. The case member 11 can be let to have a shape other than the shape shown in FIG. 1A and FIG. 1B, and moreover, an arrangement in which, the case member 11 does not have an independent form as the case member 11, is also possible.

The pressing member 21 is disposed such that, an upper surface of two end portions 21a and 21b in the longitudinal direction makes a contact with a pressing adjustment screw 36 which is inserted through two screw holes 11h formed in an upper surface of the case member 11, and a lower surface of a central portion 21c makes a contact with a supporting member 23 which is for positioning the vibrator 22. Here, the supporting member 23 is fixed to a center in the longitudinal direction (x-direction in FIG. 1A) of the vibrator 22. Moreover, the vibrator 22 is formed by an ultrasonic vibrator (such as a piezoelectric element). In the following diagrams, electric wires for driving the vibrator 22 are omitted.

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The driven member 24 is disposed on the base member 12 via the rolling members 25, 26, 27, and 28 such that, the driven member 24 is movable along the longitudinal direction of the case member 11. The driven member 24 is a member in the form of a shaft having a D-shaped cross-section, with a part of a circular cylinder cut. A flat surface portion 24a of the driven member 24 makes a contact with the vibrator 22 via a stator (a drive element) 22a, and a curved surface portion 24b of the driven member 24 makes a contact with the rolling member 25.

The base member 12 is extended along the longitudinal direction (x-direction) of the ultrasonic motor 10, and a cross-section thereof orthogonal to the longitudinal direction has a shape of an English alphabet U turned counterclockwise through 90 degrees. As shown in FIG. 1B, the rolling members 25, 26, 27, and 28 having a spherical shape make a contact with a bottom surface 12b and side surfaces 12a and 12c of the base member 12. Moreover, the driven member 24 is placed on the rolling members 25, 26, 27, and 28 such that the curved surface 24c and the rolling members 25, 26, 27, and 28 are in mutual contact. Accordingly, the driven member 24 is movable in the longitudinal direction (x-direction, direction of driving) with respect to the base member 12.

The ultrasonic motor 10 is fixed to the base member 12 by a screw 37, in a state of the pressing member 21 and the vibrator 22 accommodated inside the accommodating recess 16 of the case member 11. Thereafter, by adjusting an amount extended of the two pressing adjustment screws 36 which are screwed through the upper surface of the case member 11, inside the accommodating recess 16, front ends of the pressing adjustment screws 36 are bent by pressing both end portions 21a and 21b of the pressing member 21, and a thrust which presses the vibrator 22 against the driven member 24 is generated.

In the ultrasonic motor 10 having such structure, a positional relationship of the base member 12, the rolling members 25, 26, 27, and 28, and the driven member 24 will be described below while referring to FIG. 2 and FIG. 3. All the rolling members 25, 26, 27, and 28 have same outer diameter. Here, FIG. 2 is a cross-sectional view orthogonal to a center in a longitudinal direction (a direction (x-direction) orthogonal to y-direction and z-direction) of the case member 11 of the ultrasonic motor 10, and corresponds to an enlarged view of FIG. 1B. FIG. 3 is a cross-sectional view orthogonal to a center in a longitudinal direction (a direction (x-direction) orthogonal to y-direction and z-direction) of the case member 11 of an ultrasonic motor 110 according to a first modified embodiment of the first embodiment, and is a diagram corresponding to FIG. 2.

As shown in FIG. 2, the base member 12, at an inner side thereof, has a shape such that the side surfaces 12a and 12c which are face-to-face and the bottom surface 12b intersect mutually at right angle. The driven member 24 and the rolling members 25, 26, 27, and 28 are accommodated inside the base member 12, and each of the rolling members 25, 26, 27, and 28 makes a contact with the driven member 24, at a first contact point, and makes a contact with the base member 12 at two second contact points. Here, the rolling member 25 and the rolling member 27 are disposed along a longitudinal direction of the driven member 24. Moreover, the rolling member 26 and the rolling member 28 are disposed along the longitudinal direction of the driven member 24, to correspond to the rolling member 25 and the rolling member 27. Consequently, regarding a positional relationship of the base member 12 and the driven member 24, since the rolling members 25 and 26, and the rolling members 27 and 28 are similar, in

the following description, the rolling members **25** and **26** are described, and description of the rolling members **27** and **28** is omitted.

The positional relationship of the base member **12** and the driven member **24** will be described concretely. In the ultrasonic motor **10**, the rolling member **25** makes a contact with the driven member **24** at a contact point **25a** (a first contact point), and makes a contact with the side surface **12a** of the base member **12** at a contact point **25b** (a second contact point), and furthermore, makes a contact with the bottom surface **12b** of the base member **12** at a contact point **25c** (a second contact point). A shape of the base member **12** is set corresponding to a curvature of the curved surface portion **24b** of the driven member **24** and an outer diameter of the rolling member **25** such that, a length of a straight line **L1** connecting the contact point **25a** and the contact point **25b**, and a length of a straight line **L2** connecting the contact point **25a** and the contact point **25c** are same. Moreover, the contact point **25b** and the contact point **25c** are at positions which are symmetrical with respect to the contact point **25a**, or with respect to a straight line **L3** connecting a curvature center **24c** of the curved surface portion **24b** of the driven member **24** and the contact point **25a**, extended toward the base member **12**.

Similarly, the rolling member **26** makes a contact with the driven member **24** at a contact point **26a** (a first contact point), and makes a contact with the side surface **12c** of the base member **12** at a contact point **26b** (a second contact point), and furthermore, makes a contact with the bottom surface **12b** of the base member **12** at a contact point **26c** (a second contact point). The shape of the base member **12** is set corresponding to a curvature of the curved surface portion **24b** of the driven member **24**, and an outer diameter of the rolling member **26** such that, a length of a straight line **L4** connecting the contact point **26a** and the contact point **26b**, and a length of a straight line **L5** connecting the contact point **26a** and the contact point **26c** are same. Moreover, the contact point **26b** and the contact point **26c** are at positions which are symmetrical with respect to the contact point **26a**, or with respect to a straight line **L6** connecting the curvature center **24c** of the curved surface portion **24b** of the driven member **24** and the contact point **26a**, extended toward the base member **12**.

In the ultrasonic motor **10** having the structure as described above, when the driven member **24** is driven in the longitudinal direction (x-direction) in a state of being pushed toward the base member **12**, the rolling member **25** undergoes a rolling movement upon receiving a driving force in the longitudinal direction of the driven member **24** at the contact point **25a** with the driven member **24**. At this time, by the contact points **25b** and **25c** of the base member **12** being at positions symmetrical with respect to the extended straight line **L3**, a length of a rolling contact at the contact point **25b** and a length of a rolling contact at the contact point **25c** are same. Consequently, no slippage is generated between the rolling member **25** and the base member **12**. Furthermore, although the driven member **24** is pushed by the base member **12**, by making such structure, there is an advantage that a drag at the contact point **25b** and the contact point **25c** becomes same, and a rolling resistance at the contact points **25b** and **25c** becomes even. Such action and effect are similar also for the rolling member **26**.

Whereas, when the contact points **25b** and **25c** are assumed to be at positions asymmetrical with respect to the contact point **25a**, when the driving force is received at the contact point **25a**, a difference is generated between a rotating length on a surface of the rolling member **25** drawn by the contact point **25b** along a direction in which the rolling member **25** rotates, and a rotating length on the surface of the rolling

member **25** drawn by the contact point **25c**. Therefore, a portion making a sliding contact without making a rolling contact is generated at one of the contact point **25b** and the contact point **25c**.

Moreover, in the ultrasonic motor **110** according to the modified embodiment shown in FIG. **3**, a base member **112**, at an inner side, has a shape such that an angle made by a bottom surface **112b** and side surfaces **112a** and **112c** becomes an obtuse angle. Even in this ultrasonic motor **110**, similarly as in the ultrasonic motor **10** shown in FIG. **2**, the rolling member **25** makes a contact with the driven member **24** at the contact point **25a** (a first contact point), and makes a contact with the side surface **112a** of the base member **112** at the contact point **25b** (a second contact point), and furthermore, makes a contact with the bottom surface **112b** of the base member **112** at the contact point **25c** (a second contact point). A shape of the base member **112** is set corresponding to a curvature of the curved surface portion **24b** of the driven member **24** and the outer diameter of the rolling member **25** such that, a length of a straight line **L11** connecting the contact point **25a** and the contact point **25b**, and a length of a straight line **L12** connecting the contact point **25a** and the contact point **25c** are same. Moreover, the contact point **25b** and the contact point **25c** are at positions which are symmetrical with respect to the contact point **25a**, or with respect to a straight line **L13** connecting the curvature center **24c** of the curved surface portion **24b** of the driven member **24** and the contact point **25a**, extended toward the base member **112**. Moreover, such positional relationship is similar even for the rolling member **26**. By such an arrangement, even in this ultrasonic motor **110**, it is possible to show similar action and effect as in the ultrasonic motor **10** shown in FIG. **2**.

By making a structure as described above, since the driven member **24** is rollingly supported without being slipped, by the rolling members **25**, **26**, **27**, and **28**, it is possible to make small a transfer resistance of the driven member **24** and to reduce an output, and to reduce wearing out. Moreover, since the rolling members **25**, **26**, **27**, and **28** support not at a position exactly under z-direction (side facing the vibrator **22**) of the driven member **24** but at a position strayed off on both sides, or in other words, on sides of the side surface of the base member **12**, it is possible to make small a dimension in a direction of height (z-direction). Therefore, it is possible to make the ultrasonic motor **10** to be small-sized, involving a structure which is rollingly supported by the driven member **24** as in this embodiment.

FIG. **4** is a cross-sectional view orthogonal to a center in a longitudinal direction (direction (x-direction) orthogonal to y-direction and z-direction) of the base member **12** of an ultrasonic motor according to a second modified embodiment of the first embodiment, and is a diagram showing a positional relationship of a driven member **124**, the base member **12**, and the rolling members **25**, **26**, **27**, and **28**. As shown in FIG. **4**, a flat surface portion **124a** of the driven member **124**, which is a contact surface with the vibrator **22**, makes an angle  $\theta$  with a straight line **12d** which is extended in a horizontal direction (y-direction). Even in this case, the driven member **124** is a member in the form of a shaft having a substantially D-shaped cross-section, with a part of a circular cylinder cut, and similarly as the driven member **24** shown in FIG. **1**, the flat surface portion **124a** is in contact with the vibrator **22** via the stator **22a**, and a curved surface portion **124b** makes a contact with each of the rolling members **25**, **26**, **27**, and **28**. When the rolling member **25** is taken as an example, the rolling member **25** makes a contact with the driven member **124** at a contact point **25a** (a first contact point), and makes a contact with the side surface **12a** of the base member **12** at a

contact point **25b** (a second contact point), and furthermore, makes a contact with the bottom surface **12b** of the base member **12** at a contact point **25c** (a second contact point). The shape of the base member **12** is set corresponding to a curvature of the curved surface portion **124b** of the driven member **124**, and an outer diameter of the rolling member **25** such that, a length of a straight line **L1** connecting the contact point **25a** and the contact point **25b**, and a length of a straight line **L2** connecting the contact point **25a** and the contact point **25c** are same. Moreover, the contact point **25b** and the contact point **25c** are at positions which are symmetrical with respect to the contact point **25a**, or with respect to a straight line **L3** connecting a curvature center **124c** of the curved surface portion **124b** of the driven member **124** and the contact point **25a**, extended toward the base member **12**.

According to such positional relationship, similarly as in the ultrasonic motor **10** described in FIG. 1A, FIG. 1B, and FIG. 2, and the ultrasonic motor **110** described in FIG. 3, no slippage is generated between the rolling member **25** and the base member **12**, and a drag at the contact point **25b** and the contact point **25c** becomes same, and the rolling resistance at the contact points **25b** and **25c** becomes even. Consequently, a position of the contact point **25a** is constant, independent of the contact surface **124a** of the vibrator **22** and the driven member **24**, and the abovementioned relationship  $L1=L2$  can be maintained. Therefore, even when the driven member is inclined with respect to the horizontal direction, since the driving member **25** can undergo rolling movement, it is possible to reduce an effect of variation in assembling.

FIG. 5 is a cross-sectional view orthogonal to a center in a longitudinal direction (x-direction) of the base member **12** of an ultrasonic motor according to a third modified embodiment of the first embodiment, and is a diagram showing a positional relationship of a driven member **224**, the base member **12**, and the rolling members **25**, **26**, **27**, and **28**. As shown in FIG. 5, the driven member **224** is a member in the form of a shaft substantially trapezoidal-shaped cross-section, with an upper portion and a lower portion having a circular-cylindrical shape cut, and similarly as the driven member **24** shown in FIG. 1, a flat surface portion **224a** is in contact with the vibrator **22** via the stator **22a**, and a curved surface portion **224b** makes a contact with each of the rolling members **25**, **26**, **27**, and **28**. A positional relationship of the base member **12**, the driven member **224**, and the rolling members **25**, **26**, **27**, and **28** is similar as the ultrasonic motors shown in the diagrams from FIG. 1A to FIG. 4. When such an arrangement is made, since it is possible to reduce a size in a direction of height of the driven member **224**, it is possible to make further smaller a dimension in a direction of height of the ultrasonic motor as a whole, thereby leading to smallizing.

#### Second Embodiment

An ultrasonic motor (a linear drive ultrasonic motor) according to a second embodiment will be described below while referring to FIG. 6 and FIG. 7. Here, FIG. 6 is a cross-sectional view which is orthogonal to a longitudinal direction (direction (x-direction) orthogonal to y-direction and z-direction) of the base member **12** of the ultrasonic motor, and which passes through the rolling members **27** and **28**, and is a diagram showing a positional relationship of the driven member **24**, the base member **12**, and the rolling members **25**, **26**, **27**, and **28**. FIG. 7 is a cross-sectional view taken along a line VII-VII in FIG. 6. In the following description, same reference numerals are assigned to members, which are similar as in the ultrasonic motor according to the first embodiment.

In the ultrasonic motor according to the second embodiment, the following arrangement differs from the ultrasonic motor **10** according to the first embodiment. In other words, a guiding member **40** is disposed on the bottom surface **12b** of the base member **12**. This guiding member **40** is made by forming notches **41**, **42**, **43**, and **44**, two each in two long sides which are face-to-face, of a thin long plate. The rolling members **25**, **26**, **27**, and **28** are accommodated in the notches **41**, **42**, **43**, and **44** respectively, and are guided. The notches **41** and **43** are disposed to be separated by a predetermined distance, in one long side **40a** of the guiding member **40**, and the notches **42** and **44** are disposed to be separated by a predetermined distance, corresponding to the notches **41** and **43**, in the other long side **40b** of the guiding member **40**. According to such an arrangement, the four rolling members **25**, **26**, **27**, and **28** are disposed to maintain uniformity. Consequently, since a load on the rolling members **25**, **26**, **27**, and **28** is even, there is an effect that characteristics are stabilized. When the guiding member **40** is let to be a resin member, it is desirable since sliding of the bottom surface **12b** of the base member **12** becomes favorable.

Rest of the structure, action, and effect are similar as in the first embodiment.

#### Third Embodiment

An ultrasonic motor (a linear drive ultrasonic motor) according to a third embodiment and a modified embodiment thereof will be described below while referring to FIG. 8, FIG. 9, and FIG. 10. Here, FIG. 8 is a cross-sectional view which is orthogonal to a longitudinal direction (a direction (x-direction) orthogonal to y-direction and z-direction) of the base member of the ultrasonic motor, and which passes through the rolling members **25**, **26**, **27**, and **28**, and is a diagram showing a positional relationship of the driven member **24**, the base member **12**, and the rolling members **25**, **26**, **27**, and **28**. FIG. 9 is a cross-sectional view taken along a line IX-IX in FIG. 8. FIG. 10 is a cross-sectional view showing a positional relationship of the base member **12**, the guiding member **40**, a protruding portion **312p**, and the rolling members **25**, **26**, **27**, and **28**, and is a diagram corresponding to FIG. 9. In the following description, same reference numerals are assigned to members, which are similar as in the ultrasonic motor according to the first embodiment and the ultrasonic motor according to the second embodiment.

In the ultrasonic motor according to the third embodiment, the following arrangement differs from the ultrasonic motor **10** according to the first embodiment. In other words, as shown in FIG. 8 and FIG. 9, a protruding portion **212p** in the form of a circular cylinder at two locations is provided to a bottom surface **212b** of a base member **212**, and the guiding member **40** is disposed thereon. According to this arrangement, even when the guiding member **40** is made thin, since it is disposed at a position higher than the bottom surface **212b** of the base member **212**, the rolling members **25**, **26**, **27**, and **28** do not run on the guiding member **40**. Moreover, since it is possible to make the guiding member **40** thin, trimming of weight becomes possible, and a transfer resistance of the guiding member **40** can be reduced.

Moreover, the shape of the protruding portion **212p** is not restricted to the circular-cylindrical shape, and as shown in FIG. 10, a protruding portion **312b** by making protrude an area near two ends in a longitudinal direction (x-direction) of the base member **312**, in a direction of height, may be formed. A similar effect is achieved by such an arrangement, and it is possible to carry out a stopper function in which the rolling

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members **25**, **26**, **27**, and **28** do not come off in a longitudinal direction of the base member **12**.

Rest of the structure, action, and effect are similar as in the first embodiment.

## Fourth Embodiment

Next, a fourth embodiment and a modified embodiment thereof will be described below while referring to FIG. **11A**, FIG. **11B**, FIG. **12A**, and FIG. **12B**. Here, FIG. **11A** is a cross-sectional view showing a positional relationship of the driven member **24**, a base member **412**, and the rolling members **25**, **26**, **27**, and **28** according to the fourth embodiment, and is a diagram corresponding to FIG. **7**. FIG. **11B** is a cross-sectional view taken along a line XIB-XIB in FIG. **11A**. FIG. **12A** is a cross-sectional view showing a positional relationship of the driven member **24**, a base member **512**, and the rolling members **25**, **26**, **27**, and **28** according to the modified embodiment, and is a diagram corresponding to FIG. **7**. FIG. **12B** is a cross-sectional view taken along a line XIIB-XIIB in FIG. **12A**. In the following description, same reference numerals are assigned to members, which are similar as in the ultrasonic motor according to the first embodiment.

In an ultrasonic motor according to the fourth embodiment, the following arrangement differs from the ultrasonic motor **10** according to the first embodiment. In other words, as shown in FIG. **11A** and FIG. **11B**, notches **455**, **456**, **457**, and **458** (base guiding mechanisms) are provided to two inner-side surfaces **412a** and **412c** of a base member **512**, which are face-to-face. These notches **455**, **456**, **457**, and **458** are formed such that, a side surface is perpendicular to a bottom surface **412b** of the base member **412**, and the rolling members **25**, **26**, **27**, and **28** are disposed at an interior thereof respectively. Here, a length of a straight line connecting a contact point **428a** of the driven member **24** and the rolling member **28** and a contact point **428b** of the rolling member **28** and the side surface of the notch **458** is same as a length of a straight line connecting the contact point **428a** and a contact point **428c** of the rolling member **28** and the bottom surface **412b** of the base member **412**. In such an arrangement, when the driven member **24** is driven, the rolling members **25**, **26**, **27**, and **28** roll in a range of the notches **455**, **456**, **457**, and **458**. Consequently, since the disposing of the driven member **24**, the base member **412**, the rolling members **25**, **26**, **27**, and **28**, and the notches **455**, **456**, **457**, and **458** is determined substantially, it is possible to stabilize characteristics by making even the load on the rolling members **25**, **26**, **27**, and **28**, and the guiding member of the second embodiment and the third embodiment becomes unnecessary, thereby making it possible to reduce the number of components.

Whereas, notches **555**, **556**, **557**, and **558** (base guiding mechanisms) having a shape such that, an angle made by a bottom surface **512b** of a base member **512** and a side surface of the base member **512** is an obtuse angle may be disposed inside the rolling members **25**, **26**, **27**, and **28** respectively (FIG. **12A** and FIG. **12B**). In this case, an angle at which, a side surface of the notches **555**, **556**, **557**, and **558** intersect with the bottom surface **512b** of the base member **512** is set as follows. In other words, the angle is set to be such that, a length of a straight line connecting a contact point **528a** of the driven member **24** and the rolling member **28** and a contact point **528b** of the rolling member **28** and the side surface of the notch **558** is same as a length of a straight line connecting the contact point **528a** and a contact point **528c** of the rolling member **28** and the bottom surface **512b** of the base member **512**.

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The rest of the structure, action, and effect are similar as in the first embodiment.

In a conventional linear drive ultrasonic motor shown in FIG. **18A** and FIG. **18B**, since a mobile object **904** receives a thrust from a vibrator **901** by a pressing spring **905**, a contact portion of the mobile object **904** and a case **906** is in a state of a pressure due to the thrust acted thereon. Consequently, a frictional resistance in this contact portion becomes substantial. Furthermore, when the mobile object **904** is to be driven, a state of vibrating all the time by the vibrator **91**, or in other words, a state of being subjected to forced vibrations is assumed. Therefore, by the forced vibrations being imparted in addition to the pressure, wearing out and noise at a sliding portion of the mobile object **904** and the case **906** become a problem.

Whereas, in the ultrasonic motor according to each of the abovementioned embodiments and modified embodiments, since the structure is such that the base member, the driven member, and the rolling members are disposed such that, there is no slippage at the time of moving the driven member, the wearing out and noise can be reduced. Therefore, it is particularly effective as a guide structure of an actuator which drives by a vibrating body such as an ultrasonic vibrator.

An effect by the ultrasonic motor according to the first embodiment and the modified embodiments thereof will be described below by referring to diagrams from FIG. **13** to FIG. **15**. FIG. **13** is a side view showing a structure of an ultrasonic motor according to an example for comparison. FIG. **14** is a front view showing a structure of the ultrasonic motor according to the example for comparison. FIG. **15** is a front view showing a positional relationship of the base member and the rolling members according to the first embodiment and the modified embodiments thereof. In FIG. **13** and FIG. **14**, the case member is not shown.

In the ultrasonic motor according to the example for comparison, a point that a base member **612** is a member in the form of a flat plate, differs from the first embodiment. This base member **612** makes a contact with the rolling members **25**, **26**, **27**, and **28** at an upper surface **612a**, and the rolling members **25**, **26**, **27**, and **28** make a contact with the curved surface portion **24b** of the driven member **24**.

In the ultrasonic motor according to the example for comparison having such structure, in a case of driving the driven member **24** by making vibrate by using the vibrator **22**, the vibration is transmitted from the driven member **24** also to be base member **612** via the rolling members **25**, **26**, **27**, and **28**. In this case, since the base member **612** in the form of a flat plate is used, stiffness of the base member **612** becomes weak, and a vibration mode in which, the base member **612** is deformed by being bent in a direction of bending vibration of the vibrator **22** is susceptible to be excited. Moreover, as shown by dotted lines in FIG. **13**, without being restricted to a first-order mode of bending, even a mode of higher order is also generated. Due to generation of such vibration, the rolling members **25**, **26**, **27**, and **28**, and the driven member **24** are not stabilized, and driving characteristics are declined. Moreover, there is an increase in noise caused due to wearing out or collision at a contact portion of the rolling members **25**, **26**, **27**, and **28**, and the driven member **24**, or the base member **612**. Whereas, in a case of increasing stiffness of the base member **612** presumptively, it is necessary to increase a plate thickness of the base member **612**, which leads to making the size of the ultrasonic motor large.

On the other hand, in the ultrasonic motor according to the embodiments and the modified embodiments described above, the cross-sectional shape is let to be substantially recess-shaped (FIG. **15**) such that, the contact is made with

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the rolling members **25**, **26**, **27**, and **28** by the bottom surface **12b** and the side surfaces **12a** and **12c** of the base member **12**. When the base member **12** is let to have such cross-sectional shape, the stiffness of the base member **12** is improved, and a negative effect due to vibration such as mentioned above can be avoided. Concretely, the stiffness is improved by a side surface portion **12h** having a reinforcing function with respect to a deformation due to bending in a vertical direction (z-direction) of a bottom surface portion **12w**, and with respect to the deformation in a left-right direction (y-direction) of the side surface portion **12h**, the stiffness is improved by the bottom surface portion **12w** having the reinforcing function. Consequently, vibration of the bending deformation mode as shown in FIG. **13** is hard to be excited. Therefore, the structure of the base member according to the embodiments and the modified embodiments described above is particularly effective from a point that, it is possible to realize small-sizing and improvement in driving characteristics in a guiding structure of the actuator which is driven upon being vibrated all the time by the vibrator **22**.

Furthermore, letting the cross-sectional shape of the base member **12** to be substantially recess-shaped, at the time of incorporating the rolling members **25**, **26**, **27**, and **28**, since the rolling members **25**, **26**, **27**, and **28** are regulated in two directions namely, the side surfaces **12a** and **12c**, and the bottom surface **12b** of the base member **12**, the purpose is served only by placing the rolling members **25**, **26**, **27**, and **28** on the base member **12**. Furthermore, since an attitude of the rolling members **25**, **26**, **27**, and **28** and the driven member **24** is determined only by placing the driven member **24** from an upper side the rolling members **25**, **26**, **27**, and **28**, jig etc. of positioning is unnecessary. Therefore, there is an advantage that assemblability can be improved.

Moreover, in the second embodiment, the third embodiment, and the modified embodiments thereof, the four spherical-shaped rolling members **25**, **26**, **27**, and **28** are disposed on the base member having a shape of an English alphabet U turned counterclockwise through 90 degrees, upon being guided by guiding members or notches, and support the curved surface portion **24b** of the driven member **24**. Each rolling member makes a contact with the curved surface portion **24b** of the driven member **24** and the side surface and the bottom surface of the base member. Furthermore, the shape of the base member is set to be such that the length of two straight lines connecting the contact point of the rolling member and the driven member, and the two contact points connecting the base member and the rolling member are substantially same. According to this, since the driven member **24** is rollingly supported with respect to the base member and the rolling members **25**, **26**, **27**, and **28** without any slippage generated, even when the driven member **24** has been pushed in a direction of the base member by the pressing member **21**, the transfer resistance is reduced. Moreover, even when the driven member **24** is vibrating upon receiving drive of the vibrator **22**, since the rolling members **25**, **26**, **27**, and **28** support without being slipped with respect to the base member and the driven member **24**, the wearing out can also be reduced. Moreover, since such rollingly supporting structure is disposed at a position not right under the driven member **24** but at a position shifted toward a side, the dimension in the direction of height can be made small, and the ultrasonic motor can be structured to be small-sized as an ultrasonic motor having the driven member and the rollingly supporting structure capsuled.

In the description made above, although the lengths of the two straight lines connecting the contact point of the rolling member and the driven member, and the two contact points of

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the base member and the rolling member are focused as a target, a peculiarity of the present invention can also be described by an angle. Here, the description will be made by taking the first modified embodiment and the second modified embodiment of the first embodiment as examples. FIG. **16** is a cross-sectional view orthogonal to a center of a longitudinal direction (direction (x-direction orthogonal to y-direction and z-direction) of the base member **112** of the ultrasonic motor according to the first modified embodiment of the first embodiment, and is a diagram showing a positional relationship of the driven member **24**, the base member **112**, and the rolling members **25**, **26**, **27**, and **28**. FIG. **17** is a cross-sectional view orthogonal to the center in the longitudinal direction (x-direction) of the base member **12** of the ultrasonic motor according to the second modified embodiment of the first embodiment, and is a diagram showing a positional relationship of the driven member **124**, the base member **12**, and the rolling members **25**, **26**, **27**, and **28**.

In the first modified embodiment of the first embodiment shown in FIG. **16**, a straight line **L21** connecting the contact point **25a** of the driven member **24** and the rolling member **25**, and a center **25e** of the rolling member **25** makes an angle  $\theta 1$  with a straight line **L22** connecting the contact point **25c** of the bottom surface **112b** of the base member **112** and the rolling member **25**, and the center **25e** of the rolling member **25**. On the other hand, the straight line **L21** makes an angle  $\theta 2$  with a straight line **L23** connecting the contact point **25b** of the side surface **112a** of the base member **112** and the rolling member **25**, and the center **25e** of the rolling member **25**, and a positional relationship of the driven member **24**, the base member **112**, and the rolling member **25** is set to be such that the angle  $\theta 2$  is equal to the angle  $\theta 1$ . By having set the angles in such a manner, the rolling member **25** receives a drive from the driven member **24**. Accordingly, the rolling member **25** makes an attempt to rotate around an axis A which passes through the center **25e** of the rolling member, and which is perpendicular to the straight line **L21**.

Similarly, a straight line **L24** connecting the contact point **26a** of the driven member **24** and the rolling member **26**, and a center **26e** of the rolling member **26** makes an angle  $\theta 3$  with a straight line **L25** connecting the contact point **26c** of the bottom surface **112b** of the base member **112** and the rolling member **26**, and the center **26e** of the rolling member **26**. On the other hand, the straight line **L24** makes an angle  $\theta 4$  with a straight line **L26** connecting the contact point **26b** of the side surface **112a** of the base member **112** and the rolling member **26**, and the center **26e** of the rolling member **26**, and a positional relationship of the driven member **24**, the base member **112**, and the rolling member **26** is set to be such that the angle  $\theta 4$  is equal to the angle  $\theta 3$ . By having set the angles in such a manner, the rolling member **26** receives a drive from the driven member **24**. Accordingly, the rolling member **26** makes an attempt to rotate around an axis B which passes through the center **26e** of the rolling member **26**, and which is perpendicular to the straight line **L24**.

In the second modified embodiment of the first embodiment shown in FIG. **17**, a straight line **L31** connecting the contact point **25a** of the driven member **124** and the rolling member **25**, and the center **25e** of the rolling member **25** makes an angle  $\theta 5$  with a straight line **L32** connecting the contact point **25c** of the bottom surface **12b** of the base member **12** and the rolling member **25**, and the center **25e** of the rolling member **25**. On the other hand, the straight line **L31** makes an angle  $\theta 6$  with a straight line **L33** connecting the contact point **25b** of the side surface **12a** of the base member **12** and the rolling member **25**, and the center **25e** of the rolling member **25**, and a positional relationship of the driven mem-

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ber 124, the base member 12, and the rolling member 25 is set to be such that the angle  $\theta 6$  is equal to the angle  $\theta 5$ . By having set the angles in such a manner, the rolling member 25 receives a drive from the driven member 124. Accordingly, the rolling member 25 makes an attempt to rotate around an axis D which passes through the center 25e of the rolling member 25, and which is perpendicular to the straight line L31.

Similarly, a straight line L34 connecting the contact point 26a of the driven member 124 and the rolling member 26, and the center 26e of the rolling member 26 makes an angle  $\theta 7$  with a straight line L35 connecting the contact point 26c of the bottom surface 12b of the base member 12 and the rolling member 26, and the center 26e of the rolling member 26. On the other hand, the straight line L34 makes an angle  $\theta 8$  with a straight line L36 connecting the contact point 26b of the side surface 12a of the base member 12 and the rolling member 26, and the center 26e of the rolling member 26, and a positional relationship of the driven member 124, the base member 12, and the rolling member 26 is set to be such that the angle  $\theta 8$  is equal to the angle  $\theta 7$ . By having set the angles in such a manner, the rolling member 26 receives a drive from the driven member 124. Accordingly, the rolling member 26 makes an attempt to rotate around an axis D which passes through the center 26e of the rolling member 26, and which is perpendicular to the straight line L34.

## INDUSTRIAL APPLICABILITY

As it has been described above, the linear drive ultrasonic motor according to the present invention is appropriate for a highly accurate drive of a small-size equipment.

The invention claimed is:

1. A linear drive ultrasonic motor comprising at least:
  - an ultrasonic vibrator having a piezoelectric element;
  - a driven member which is driven by a frictional force between the driven member and the ultrasonic vibrator;
  - a pressing member which presses the ultrasonic vibrator such that, a frictional force is generated between the ultrasonic vibrator and the driven member;
  - a rolling member having a spherical shape, which makes a contact with the driven member; and

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a base member which movably supports the driven member via the rolling member; wherein the rolling member makes a contact with the driven member at a first contact point, and makes a contact with the base member at two second contact points, and lengths of two straight lines connecting the first contact point and two second contact points are substantially same.

2. The linear drive ultrasonic motor according to claim 1, wherein the driven member has a curved surface within a range in which, at least the first contact point exists.

3. The linear drive ultrasonic motor according to claim 1, wherein the rolling member is disposed at a position which is not exactly under the driven member.

4. The linear drive ultrasonic motor according to claim 1, comprising:

a guiding member which includes a plurality of rolling members, and which guides the rolling members in a direction in which the driven member is driven, while maintaining a relative positional relationship of the rolling members.

5. The linear drive ultrasonic motor according to claim 4, wherein a protruding portion which is lower than a radius of the rolling member is provided at a bottom surface of the base member.

6. The linear drive ultrasonic motor according to claim 1, wherein a base guiding mechanism which includes a plurality of rolling members, and which guides the rolling members in a direction in which, the driven member is driven, while maintaining a relative positional relationship of the rolling members, is provided to the base member.

7. The linear drive ultrasonic motor according to claim 1, wherein the base member has a flat surface corresponding independently to each of the two second contact points, toward the rolling member.

8. The linear drive ultrasonic motor according to claim 7, wherein in the base member, an angle made by adjacent flat surfaces is a right angle.

9. The linear drive ultrasonic motor according to claim 7, wherein in the base member, an angle made by adjacent flat surfaces is an obtuse angle.

\* \* \* \* \*